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February 1994

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Bluestone Phase 2 Temperature and Dissolved Oxygen Modeling Study

by Dorothy H. Tillman, Thomas M. Cole
Environmental Laboratory

WES

Prepared for U.S. Army Engineer District, Huntington

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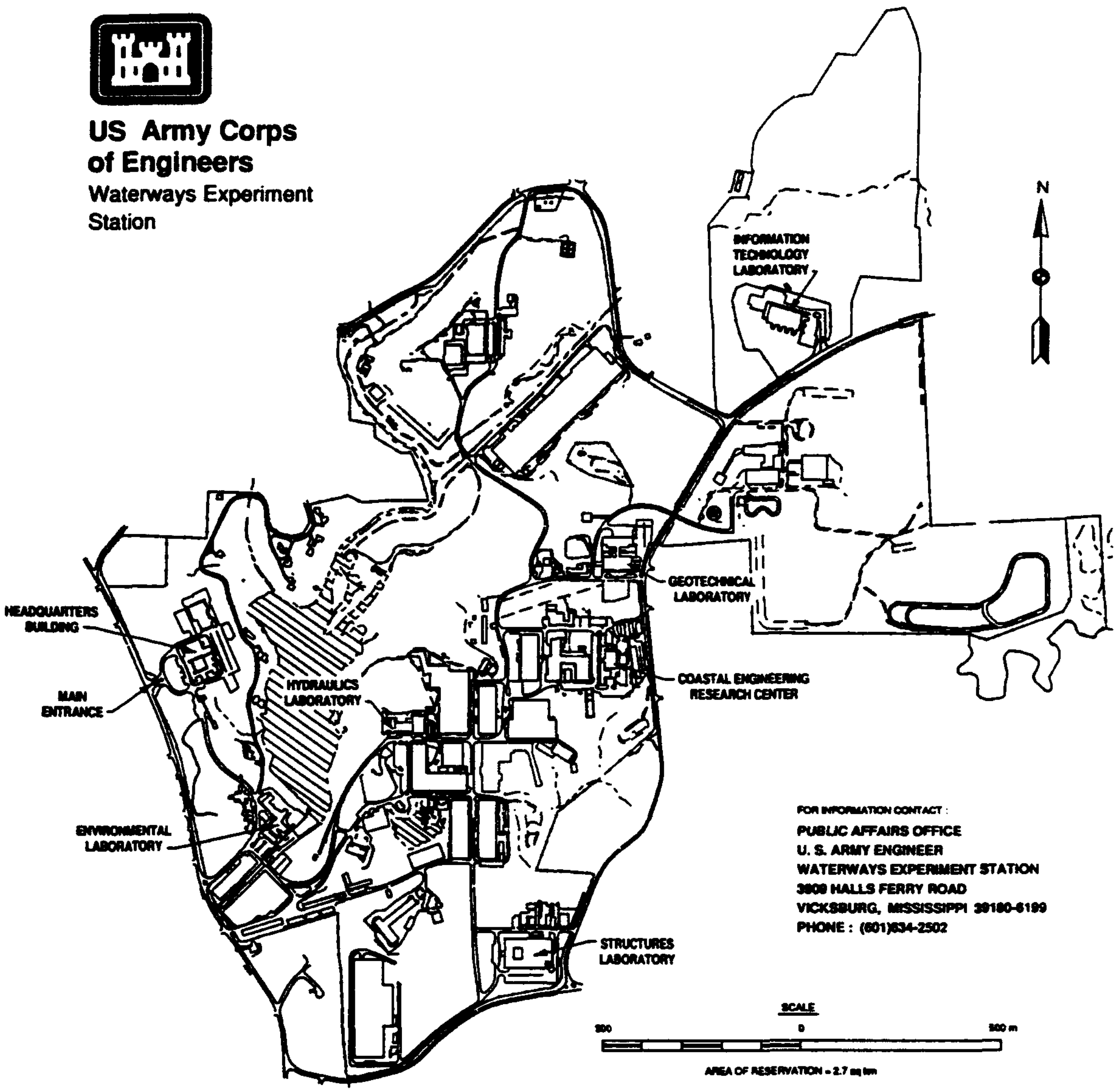

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Contents

List of Figures

Preface

The report herein presents results of a modeling study on Bluestone Reservoir, WV. The model (CE-QUAL-W2) was used to determine the effects of increased pool elevation and hydropower retrofitting on in-pool and release temperature and dissolved oxygen. This report was prepared in the Environmental Laboratory (EL), U.S. Army Engineer Waterways Experiment Station (WES), Vicksburg, MS. The study was sponsored by the U.S. Army Engineer District, Huntington, and was funded under the Military Interdepartmental Purchase Request No. E8593HW01 dated 27 October 1992.

The Principal Investigators of this study were Ms. Dorothy H. Tillman and Mr. Thomas M. Cole of the Water Quality and Contaminant Modeling Branch (WQCMB), Environmental Processes and Effects Division (EPED), EL. This report was prepared by Ms. Tillman and Mr. Cole under the direct supervision of Dr. Mark Dortch, Chief, WQCMB, and under the general supervision of Mr. Donald L. Robey, Chief, EPED, and Dr. John Harrison, Director, EL. Technical reviews by Drs. Dortch and Barry Bunch, WQCMB, are gratefully acknowledged.

At the time of publication of this report, Director of WES was Dr. Robert W. Whalin. Commander was COL Bruce K. Howard, EN.

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Conversion Factors, Non-SI to SI Units of Measurement

Non-SI units of measurement used in this report can be converted to SI units as follows:

Multiply	By	To Obtain
acres	4,046.873	square meters
cubic feet	0.02831685	cubic meters
feet	0.3048	meters
miles (U.S. statute)	1.609347	kilometers
square miles	2.589998	square kilometers

1 Introduction

Background

The U.S. Army Engineer District, Huntington, is presently considering raising the pool at Bluestone reservoir 11 ft[1] and adding conventional, base-load hydropower. Through the Water Operations Technical Support (WOTS) program, the Huntington District contacted the U.S. Army Engineer Waterways Experiment Station (WES) Environmental Laboratory for recommendations on evaluating effects to water quality if the proposed modifications were made.

Personnel from WES met with the Huntington District and discussed evaluation of future water quality conditions at Bluestone Lake, WV. Recommendations were made on the approach to determine effects of project modifications and included three phases: (a) apply the SELECT model (Davis et al. 1987) to evaluate potential dissolved oxygen (DO) of release water with hydropower assuming no change in in-pool conditions, (b) apply the time-varying, two-dimensional (laterally averaged) hydrodynamic and water quality model, CE-QUAL-W2, to evaluate potential changes in in-pool and release temperature and DO assuming a gross water column oxygen demand for DO, and (c) apply CE-QUAL-W2 with all water quality state variables activated to more accurately define potential changes in future in-pool and release DO instead of having to make broad assumptions about the depletion rate.

Phase 1 of the Bluestone Water Quality Study was completed by personnel at the Huntington District with guidance from the WES Hydraulics Laboratory. The WES Environmental Laboratory conducted Phase 2 as requested by the Huntington District. Results from Phase 2 are presented in this report.

Study Objective

The Environmental Laboratory assisted the Huntington District by conducting the Phase 2 numerical modeling of temperature and DO in

[1] A table of factors for converting non-SI units of measurement to SI units is presented on page vi.

Bluestone Lake, WV. Model results from CE-QUAL-W2 scenario runs were used to evaluate potential changes in in-pool and release temperature and DO by raising the pool 11 ft and adding hydropower to the project.

General Modeling Approach

This study involved applying the two-dimensional (laterally averaged) hydrodynamic and water quality model, CE-QUAL-W2, to Bluestone Lake for temperature and DO only. DO was modeled in a simplified manner using a gross water column oxygen demand (WCOD) and a sediment oxygen demand (SOD). This approach results in more uncertainty for DO predictions. The DO rate parameters were adjusted to match 2 years (a wet year,1983, and dry year, 1981) of observed data. The assumption in this approach is that the change in pool will not affect the WCOD and SOD rates. This assumption can not be confirmed without proceeding to the recommended third phase. The benefit of this study was to have more confidence and greater resolution (in terms of time discretization and accuracy of release DO results) than the first phase study recommended by WES in determining impacts. Sensitivity analyses were also run by adjusting the SOD and WCOD rates in the calibration and verification control data sets to see which parameter had a greater effect on DO.

After calibration/verification, two scenario runs were made: (a) raising the pool 11 ft and (b) raising the pool 11 ft and adding hydropower. Comparisons were made between calibration/verification results and scenario results for both years to determine impacts to temperature and DO on in-pool and release concentrations.

Site Description

Bluestone Dam has impounded the New River near Hinton, WV (Figure 1), since December 1949. It was constructed for various purposes, including flood control, recreation, and fish and wildlife enhancement. Two major tributaries drain into Bluestone Lake, New River and Bluestone River, for a total drainage area of 4,565 square miles. At normal summer pool (1,410 ft from 1 April through 29 November), the surface area of 2,039 acres is created with a backwater of 10.8 miles. At normal winter pool (1,406 ft from 1 December through 29 March), the surface area of 1,800 acres is created with a backwater of 9.5 miles. The maximum pool elevation for flood control is 1,520 ft and creates a backwater of 36 miles. A mean hydraulic retention time of 6 days is estimated using the 1985 growing season discharge of 3,183 cfs.

Bluestone Dam is a concrete gravity dam structure having an overall height of 165 ft with the top elevation at 1,535 ft and bottom elevation at 1,369 ft. Maximum depth of the reservoir is approximately 60 ft for normal summer pool. Discharge is through 16 gated sluices that each measure

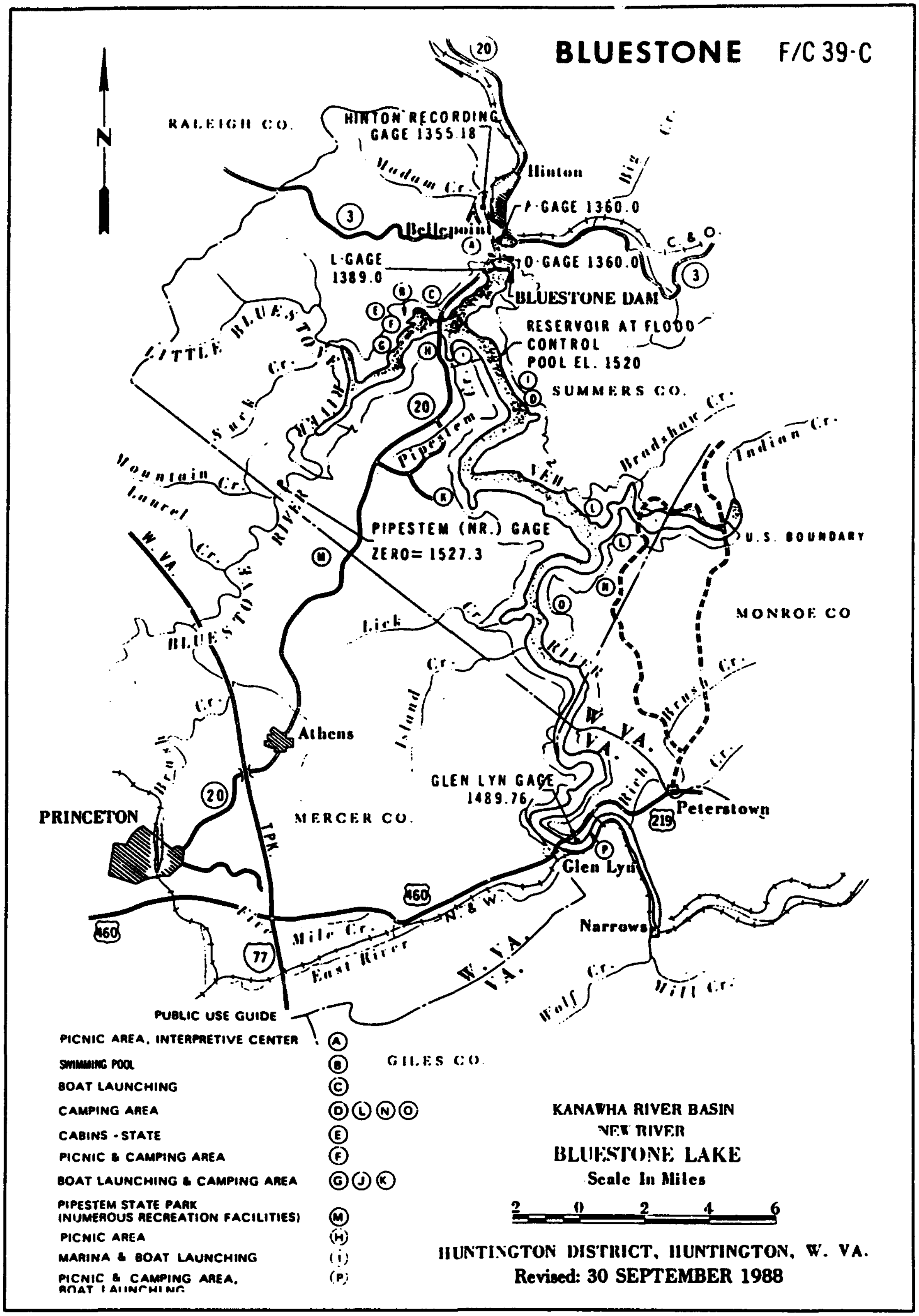


Figure 1. Bluestone Lake

5 ft 8 in. wide by 10 ft high, and the center line of the openings are at elevation 1,394 ft. Penstocks have been installed for future installation of hydropower with the center line of intakes at elevation 1,383 ft. Discharge from Bluestone Lake ranges from approximately 1,000 to 40,000 cfs.

2 Model Description

Model Discussion

CE-QUAL-W2 is a two-dimensional model that predicts vertical and longitudinal variations in hydrodynamics, temperature, and constituents in a water body through time. The model is based upon the Generalized Longitudinal-Vertical Hydrodynamics and Transport (GLVHT) model of rivers, reservoirs, and estuaries (Buchak and Edinger 1984). Earlier versions were known as the Laterally Averaged Reservoir Model (LARM) (Buchak and Edinger 1982). Development of the GLVHT model has been ongoing since 1975 by WES and J. E. Edinger and Associates of Wayne, PA. The GLVHT has been previously used to simulate temperature distributions and circulation patterns in water bodies and has been applied to a variety of systems (Buchak and Edinger 1984). The main modifications to the GLVHT model resulting in CE-QUAL-W2 were the inclusion of the algorithms to simulate water quality constituents.

CE-QUAL-W2 is based upon a finite difference solution of the laterally averaged equations of fluid motion including the following: (a) the free water surface, (b) hydrostatic pressure, (c) horizontal momentum, (d) continuity, (e) constituent transport, and (f) an equation of state relating density and constituents including temperature and solids concentrations (dissolved and suspended). By solving for the water surface elevation implicitly, the restrictive Courant surface gravity wave criterion is removed, allowing simulation of reasonable time frames for field applications, such as entire stratification cycles. An explicit scheme is then used to transport heat and chemical/biological constituents. The model has the capability of including head or flow boundary conditions, branches, multiple withdrawals, and other features that allow its application to a variety of situations.

Basic features of CE-QUAL-W2 are summarized below:

a. Two-dimensional (laterally averaged) simulations of temperatures, constituents, and flow fields.

b. Hydrodynamic computations influenced by variable water density caused by temperature and dissolved and suspended solids.

c. Simulation of the interactions of numerous biological/chemical factors influencing water quality.

d. Allowance for multiple inflow loadings and withdrawals from tributaries, point and nonpoint sources, precipitation, branch inflows, and outflows from a dam.

e. Allowance for multiple branches.

f. Allowance for ice cover computations.

g. Allowance for variable time steps.

h. Allowance for flow or head boundary conditions, making it applicable for reservoir or estuarine modeling.

i. Simulation of circulation patterns.

j. Restart capability.

k. Inclusion of evaporation in water balance.

l. Heat transfer computations.

m. Variety of output options.

n. Selective withdrawal capabilities.

CE-QUAL-W2 conceptualizes the reservoir as a grid consisting of a series of vertical columns (segments) and horizontal rows (layers), with the number of cells equal to the number of segments times the number of rows. The basic parameters used to define the grid are the longitudinal spacing (Δx, in meters) and the vertical spacing (h, in meters). The vertical spacing and the longitudinal spacing may vary spatially. Each cell also has an associated width that represents an average value.

CE-QUAL-W2 currently simulates 20 water quality constituents in addition to temperature and circulation patterns. Many of the constituents are simulated simply to include their effects upon other constituents of interest. The constituents are separated into four levels of complexity, permitting flexibility in model application. The first level (Table 1) includes materials that are conservative, noninteractive, or do not affect other materials in the first level. The second level (Table 1) allows the user to simulate the interactive dynamics of oxygen-phytoplankton-nutrients. The third level (Table 1) allows simulation of pH and carbonate species, and the fourth level allows simulation of total iron, which is important during anoxic conditions. The model calculates in-pool water volumes, surface elevations, densities, vertical and longitudinal velocities, temperatures, and constituent concentrations as well as downstream release concentrations.

Table 1
Water Quality Constituent Levels

Level 1	
Conservative tracer	Coliform bacteria
Inorganic suspended solids	Total dissolved solids or salinity
Level 2	
Labile dissolved organic matter	Ammonia-nitrogen
Refractory dissolved organic matter	Nitrate-nitrogen
Phytoplankton	Dissolved oxygen
Detritus	Organic sediments
Phosphate-phosphorus	
Level 3	
Dissolved inorganic carbon	Carbon dioxide
Alkalinity	Bicarbonates
pH	Carbonates
Level 4	
Total iron	

Data Requirements

CE-QUAL-W2 requires a database that includes in-pool initial conditions, reservoir geometry, physical coefficients, biological and chemical reaction rates, and time sequences of hydrometeorological and inflowing water quality quantities. Observed release water quality data is also needed to evaluate predicted release conditions. Calibration/verification is highly dependent on the availability of in-pool water quality constituent concentrations at several locations within the reservoir.

3 CE-QUAL-W2 Calibration/Verification

Calibration/Verification Data Sources

The model was calibrated and verified for a dry and wet water year (1981 and 1983, respectively). The different data types necessary to calibrate and verify CE-QUAL-W2 for the Bluestone system were as follows:

a. In-pool temperature and DO data for various stations in Bluestone Lake.

b. Release data.

c. Bathymetry data.

d. Tributary inflow rates and constituent concentrations.

e. Meteorological data.

f. Water surface elevation data.

g. Dam outlet specifications.

h. Reservoir elevation-area-capacity table.

The Huntington District provided the observed in-pool, release, water surface elevations, and calculated inflow data for the 2 study years. The Huntington District also provided the sediment range survey data used in calculating the reservoir geometry, elevation-volume curve, and the plans from the proposed hydropower study. Inflow temperature data were obtained from CD ROM for the U.S. Geological Survey station New River at Glen Lyn, VA (station number 03176500). Meteorological data were obtained from the U.S. Air Force Environmental Technical Applications Center in Asheville, NC, for the Roanoke, VA, and Beckley, WV, first-order meteorological stations. Data from the Roanoke station were used for calibration and verification because the Beckley station was missing data for the year selected for verification.

Observed in-pool data were available on a monthly basis for both years. During 1981 (calibration), observed data were available for the months of April through September. Consequently, the calibration period was limited to these months. Likewise for verification, observed data were available only for the months of May through October, which limited the simulation period to these months.

Calibration

Before actual calibration of temperature and DO could be conducted, the water balance of Bluestone Lake had to be accomplished. Adjustments to the bathymetry data and the elevation of the bottom datum were made to correct water imbalances in the system. These parameters were adjusted until the predicted elevations and volumes satisfactorily matched the elevation-area-capacity data provided by the Huntington District (Figure 2). An elevation-volume relationship was also developed from the data that predicted the water

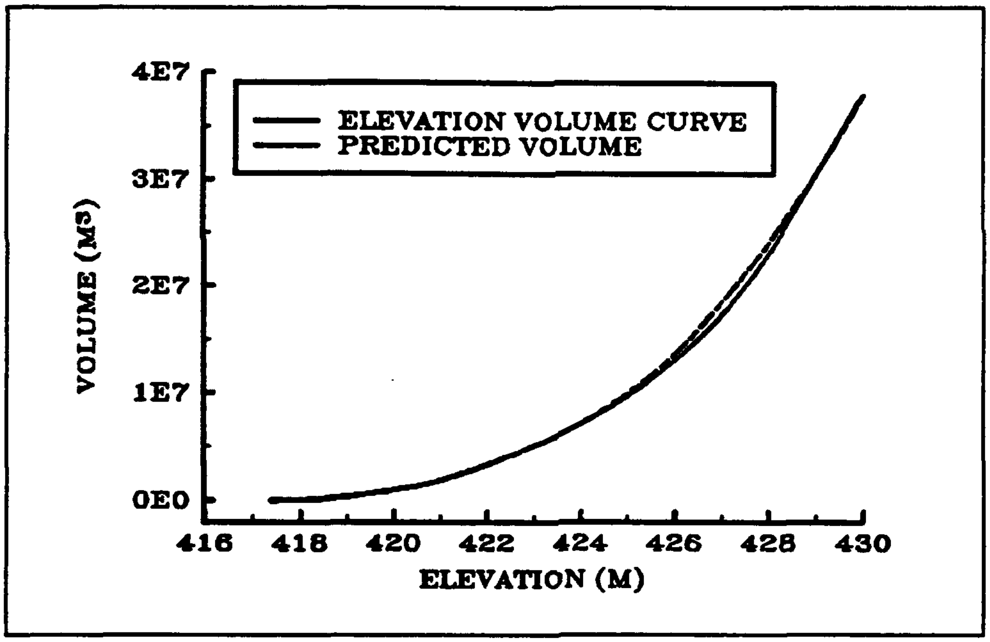


Figure 2. Elevation-volume curve

surface elevations (WSEL) based on initial reservoir volume, inflows, and outflows of Bluestone Lake! This relationship was used to check for erroneous values in the inflow and outflow data. Based on the volume change resulting from the values of inflows and outflows being used, the predicted WSEL for 1981 did not match what had been observed. The predicted WSEL varied more than 30 ft for some days where the measured data showed very little change. After consultation with personnel at the Huntington District, it was suggested that inflows calculated by the Huntington District be used instead of the U.S. Geological Survey data since the Glen Lyn station had problems during the 1980s. Once the calculated inflow data were used, predicted WSEL

were well within the 0.5-m error considered acceptable (Environmental Laboratory and Hydraulics Laboratory 1986). In fact, the predicted WSEL were almost a perfect overlay of the observed values (Figure 3) excluding minor errors (i.e., less than 0.1 m for short periods).

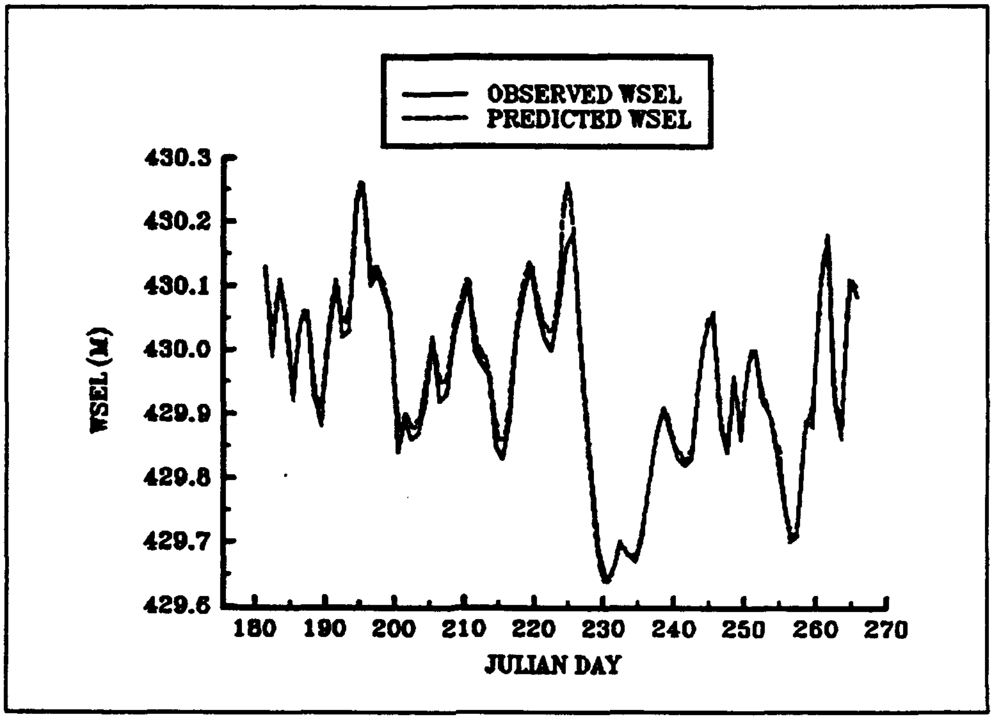


Figure 3. Predicted versus observed WSEL for 1981

Satisfactory results for hydraulic calibration allowed initiation of water quality calibration. Temperature was calibrated first, since DO is temperature dependent. During temperature calibration, adjustments were made to the Chezy coefficient and wind sheltering coefficient (Appendix A). They were initially set to values recommended in the user's manual (Environmental Laboratory and Hydraulics Laboratory 1986). Adjusting these parameters improved temperature predictions. However, only after restricting the lower limit of selective withdrawal to elevation 1,387 ft, was the thermocline predicted correctly. Bluestone temperature profiles show more stratification than would be expected from a reservoir having such a short retention time (approximately 6 days at the most). For instance, hypolimnetic temperatures would have been expected to increase as the summer progressed. However, the observed data showed very small changes in hypolimnetic temperatures throughout the summer, especially in 1983 (see Figures 4 and 5). It is unclear why restriction of selective withdrawal was necessary, but it was originally believed that a coffer dam was in place upstream of the dam. After checking with District personnel, it was found out that this was not the case. Other reasons for having to restrict the selective withdrawal may be that sedimentation has occurred near the dam since the last sediment range survey or groundwater seepage is

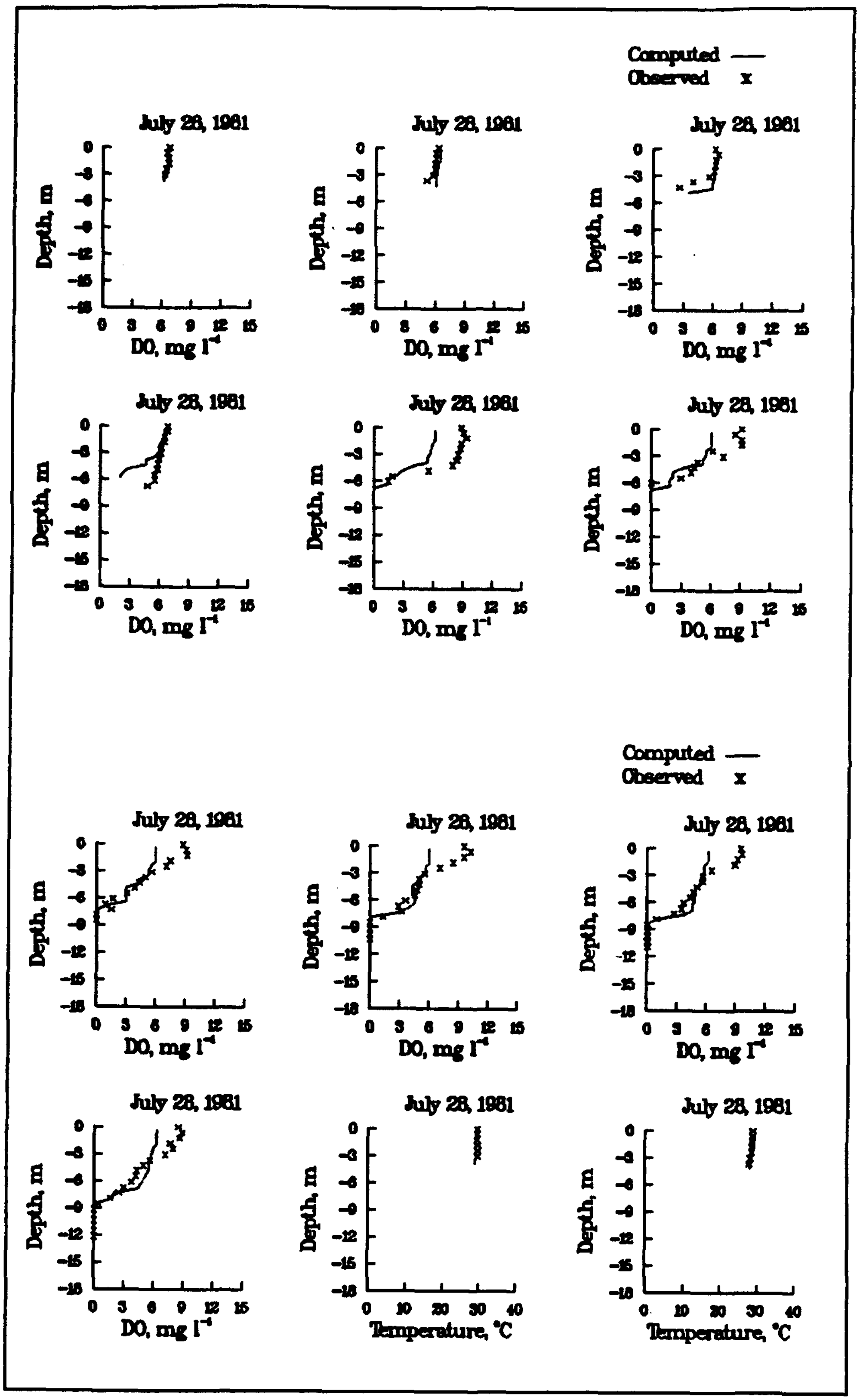


Figure 4. Final calibration results for DO and temperature (predicted versus observed) (Sheet 1 of 5)

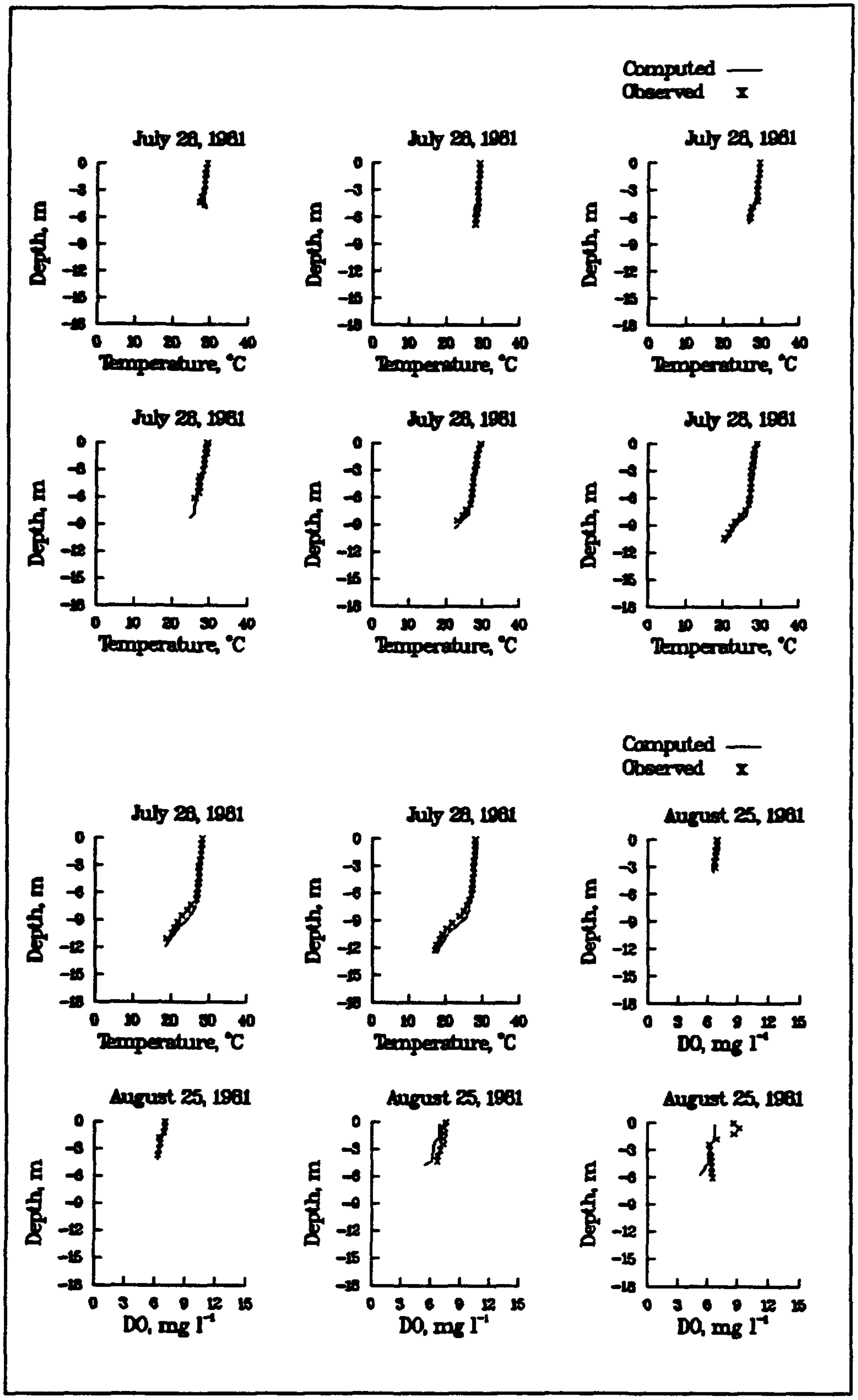


Figure 4. (Sheet 2 of 5)

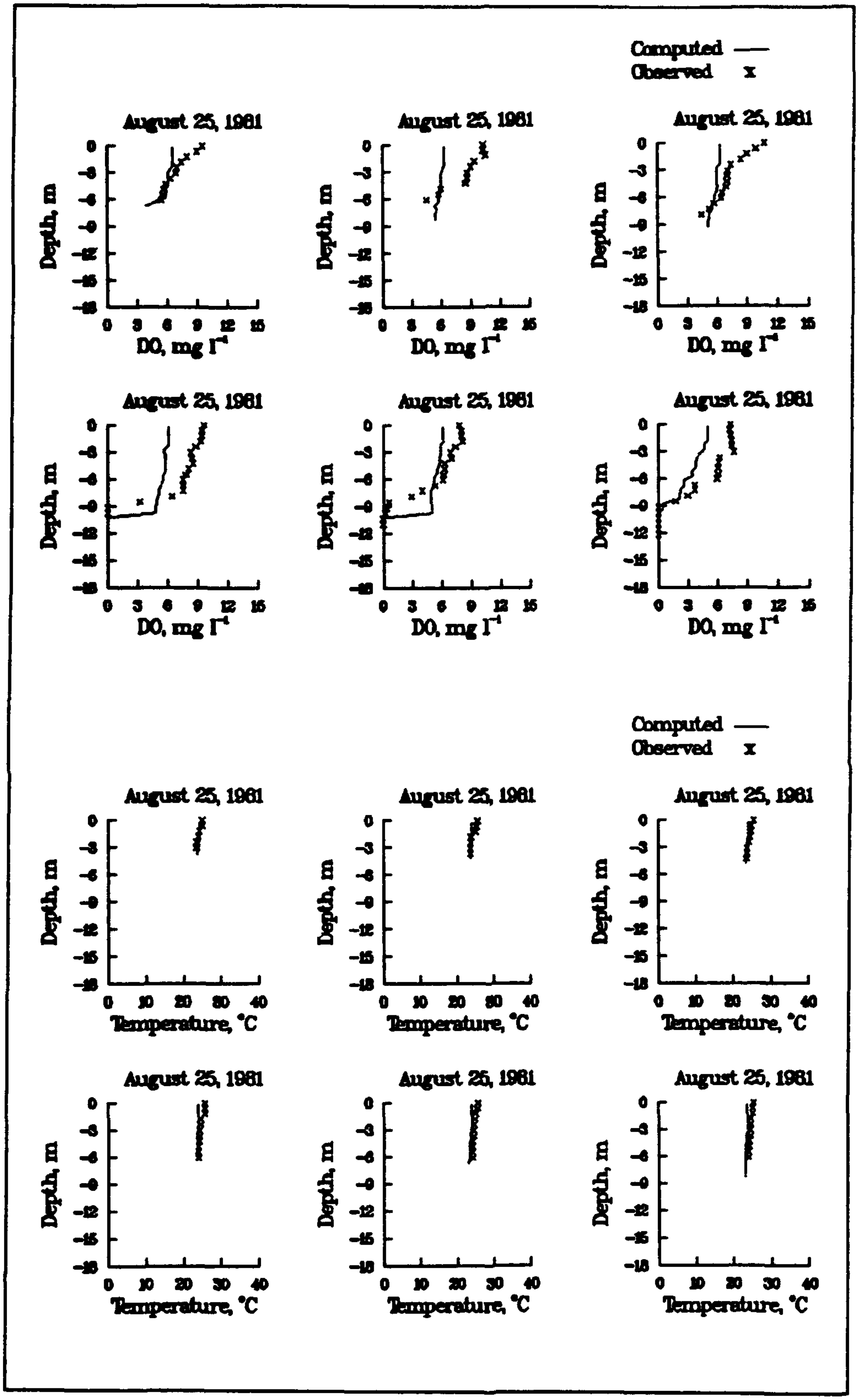


Figure 4. (Sheet 3 of 5)

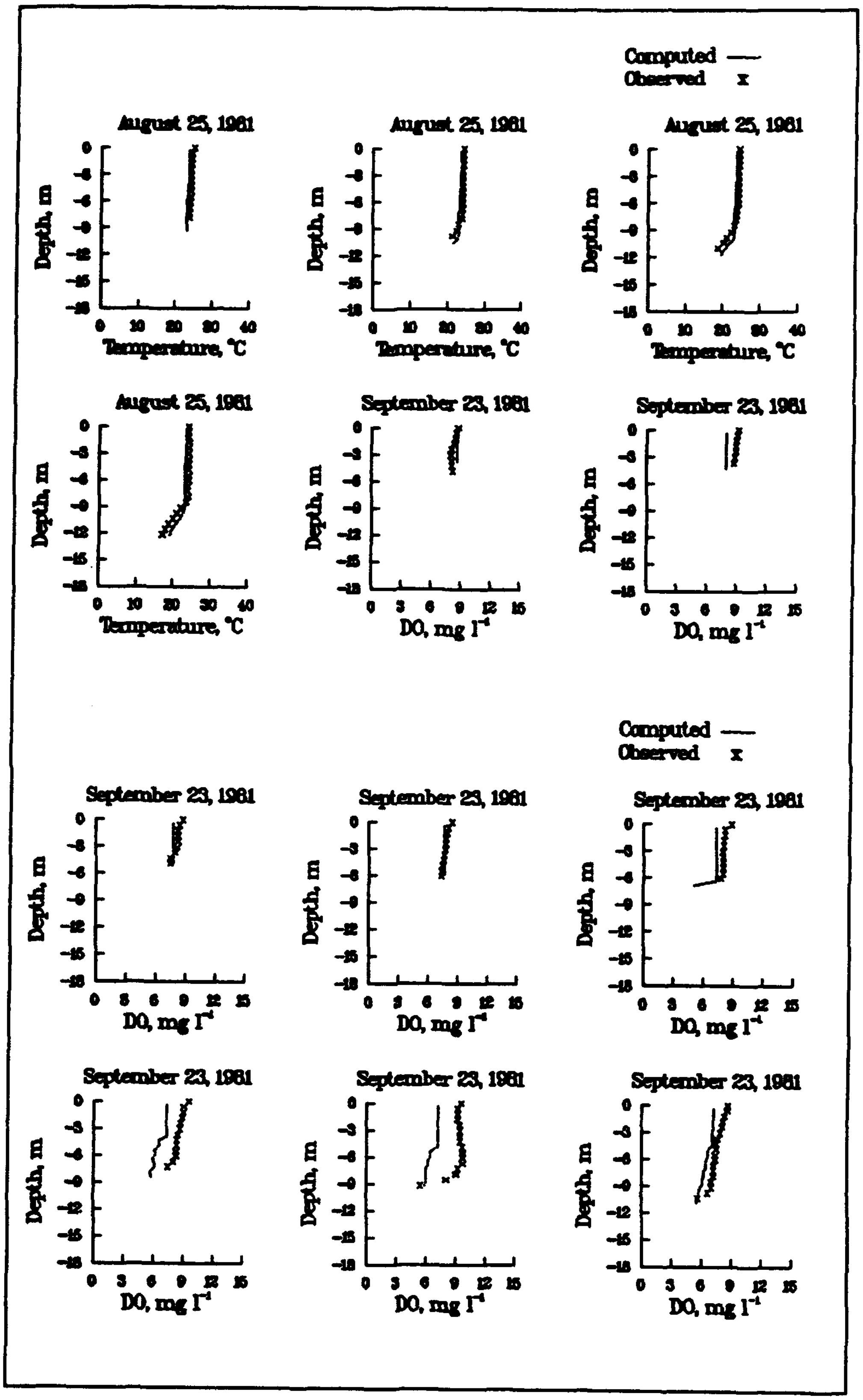


Figure 4. (Sheet 4 of 5)

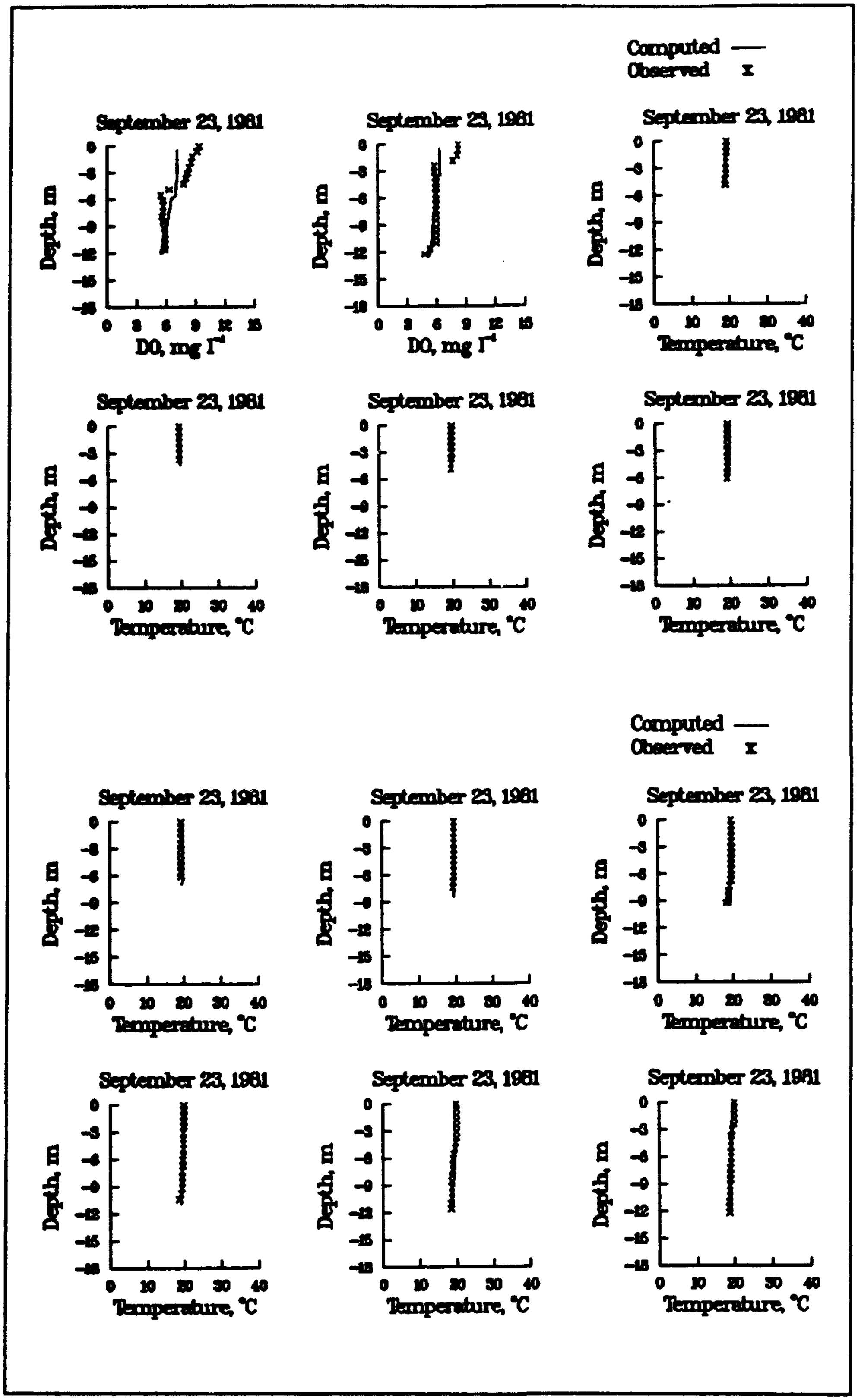


Figure 4. (Sheet 5 of 5)

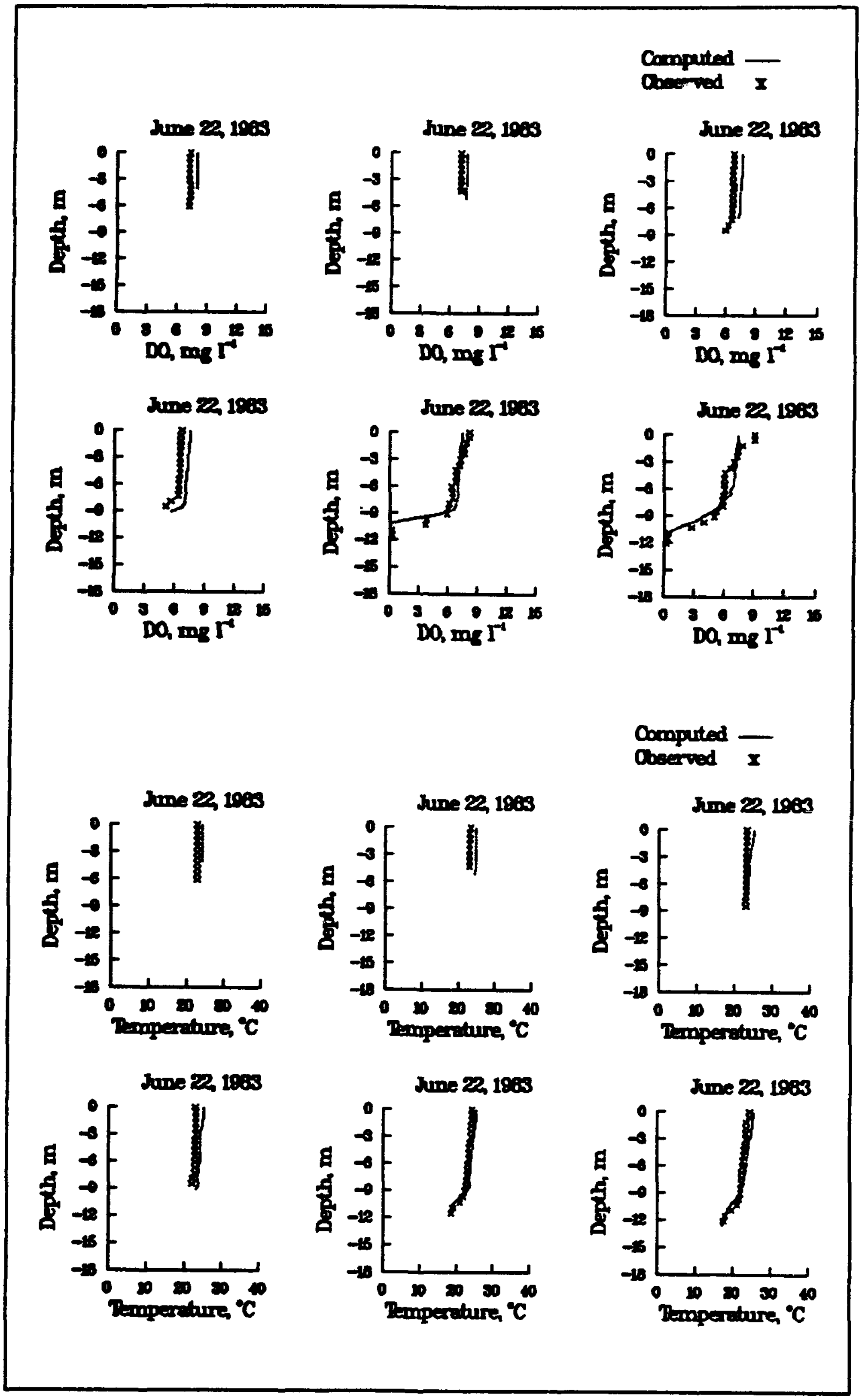
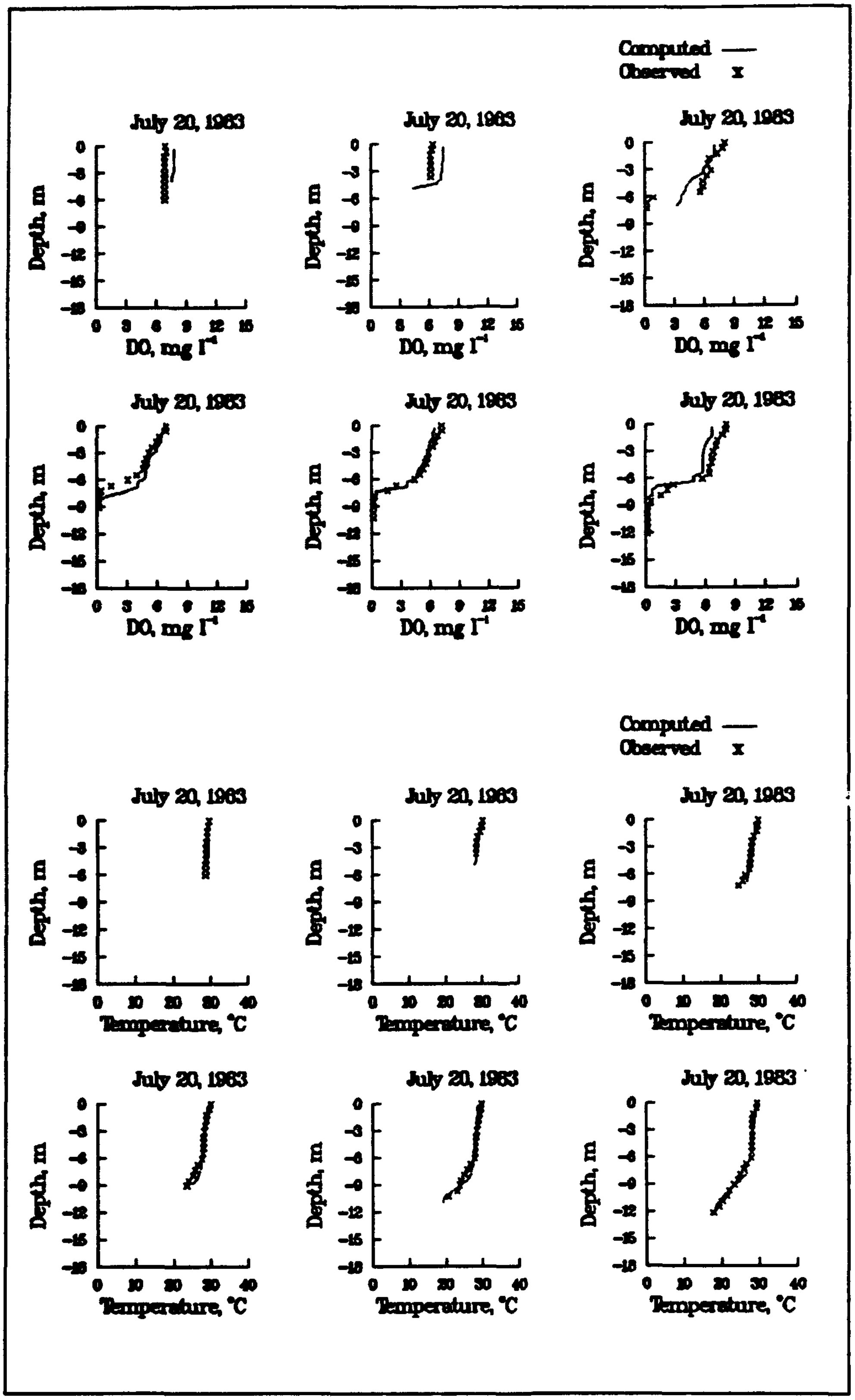


Figure 5. Final verification results for DO and temperature (predicted versus observed) (Sheet 1 of 5)



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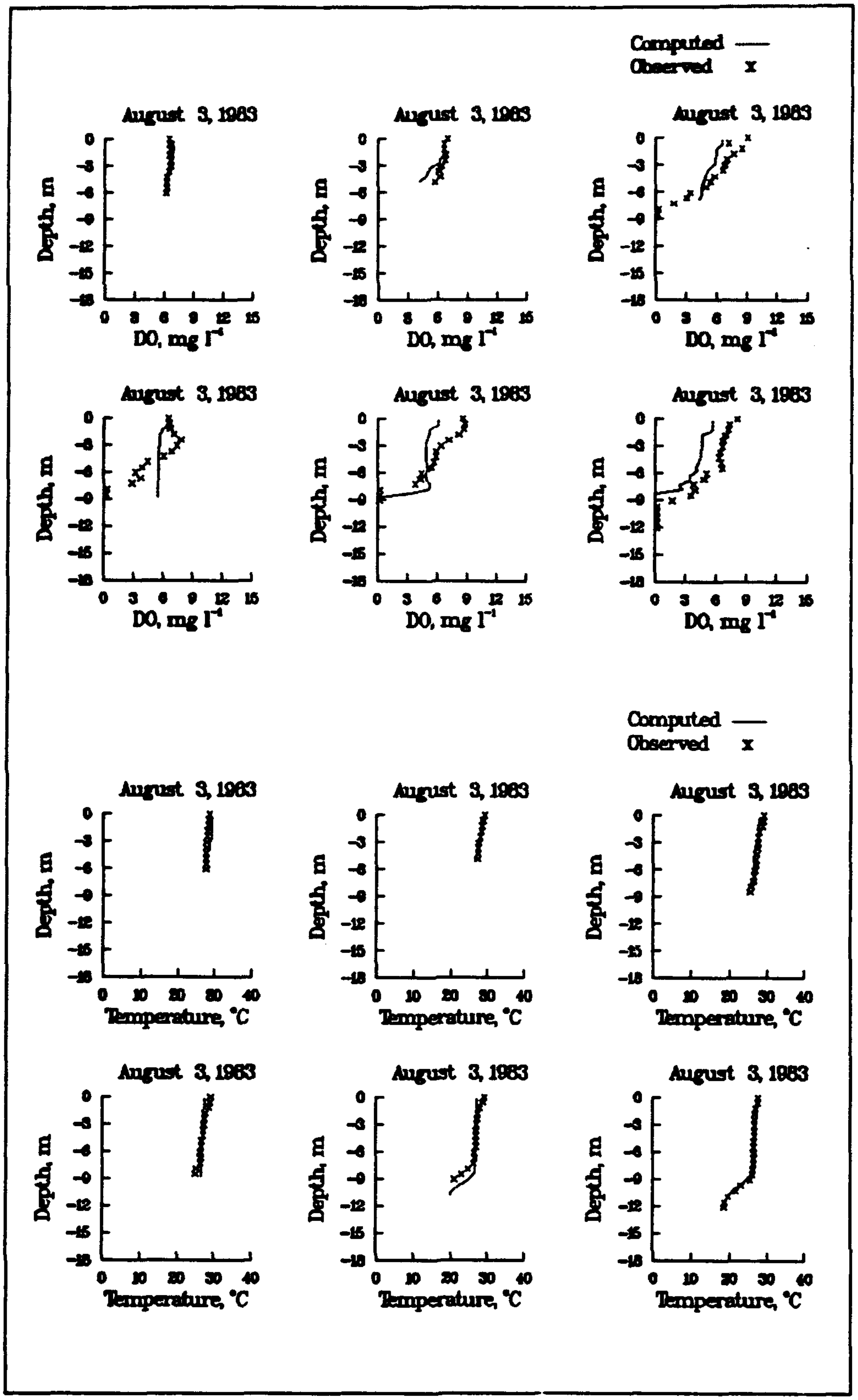

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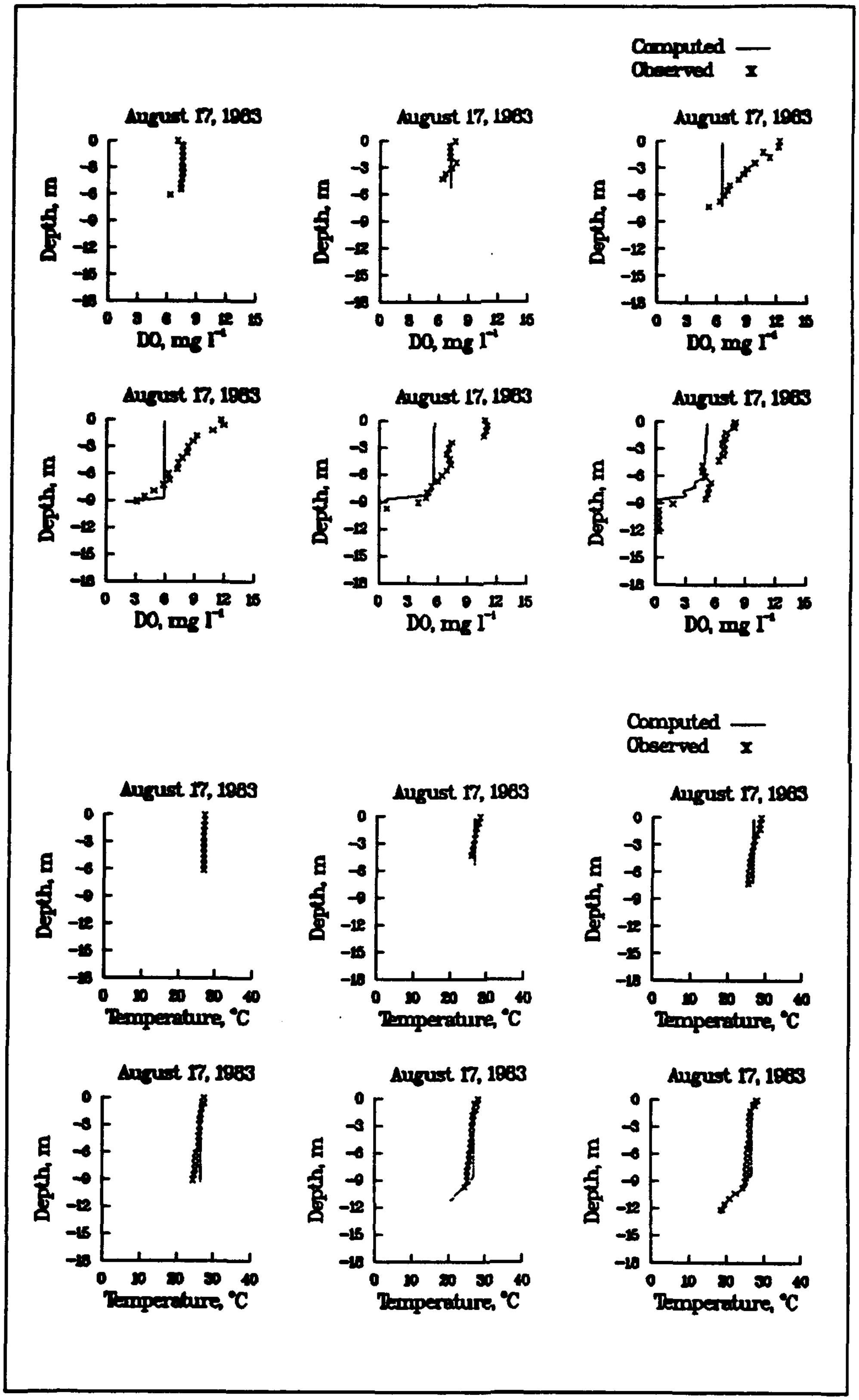

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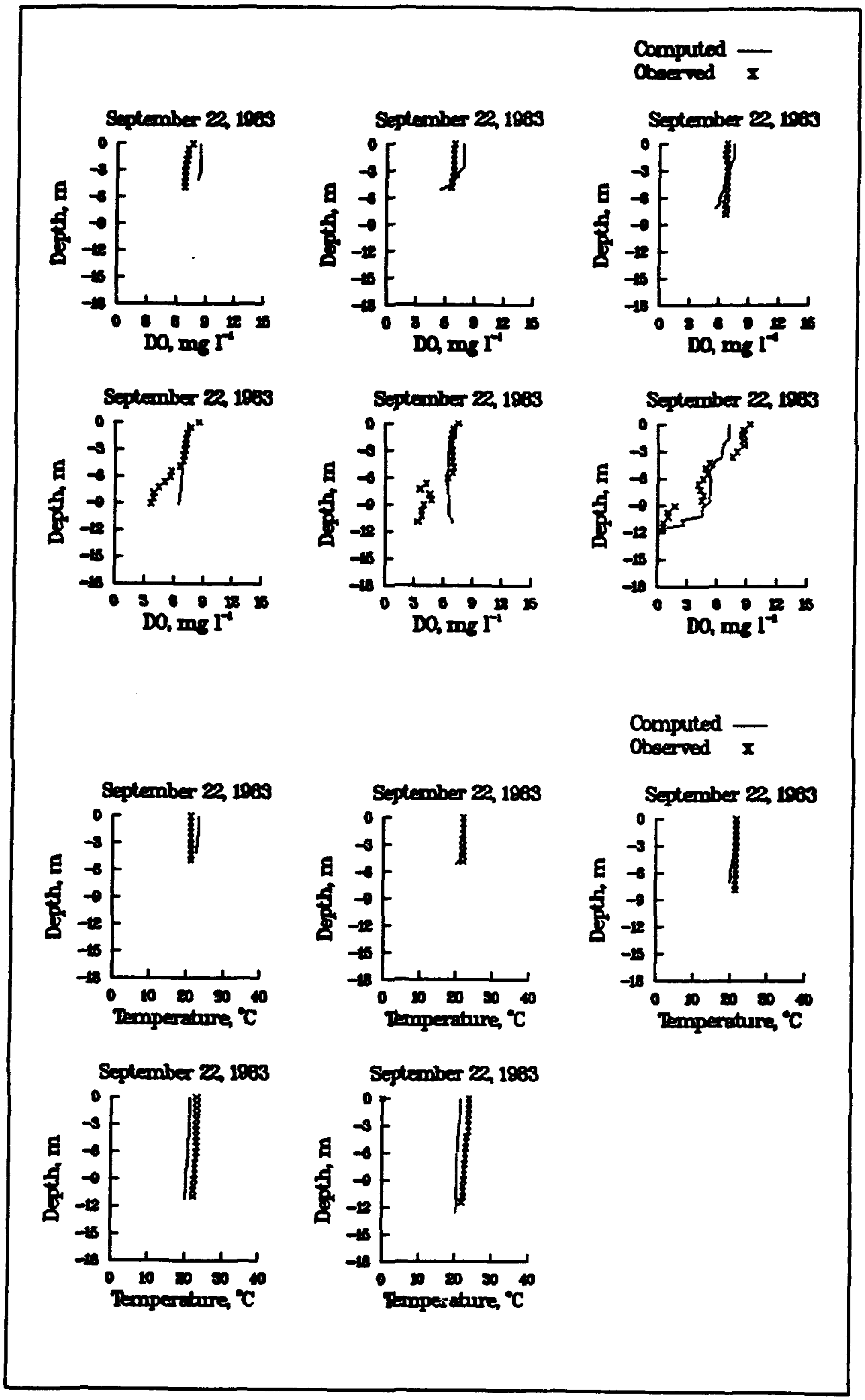

Figure 5. (Sheet 5 of 5)

cooling the hypolimnetic waters. District personnel may want to investigate this further.

Temperature and DO profile results for calibration are shown in Figure 4. Ten observed temperature and DO profile data stations were available in 1981 for comparison to predicted temperature and DO profiles. Table 2 lists the observed in-pool stations and the location of each in relation to Bluestone Dam. In Figure 4, DO and temperature profiles are presented for each observed Julian day. DO profiles are plotted first beginning with the most upstream station proceeding in the downstream direction with the temperature profiles for the same day plotted next in the same order. For example, in Figure 4, the first observed Julian day is 28 July 81, and the order of the DO profile stations is 1BLN20014, 1BLN20013, 1BLN20012, 1BLN20011, 1BLN20010, 1BLN20009, 1BLN20003, 1BLN20008, 1BLN20007, and 1BLN20002. The temperature profiles for that day follow in the same order.

Table 2
Observed Profile Stations

Station No.	Distance from Dam, miles	Segment No.	1981[a]	1983[a]
1BLN20002	0.25	31	X	X
1BLN20007	1.00	29	X	
1BLN20008	2.00	28	X	X
1BLN20003	2.90	26	X	X
1BLN20009	4.00	25	X	
1BLN20010	5.00	22	X	X
1BLN20011	6.00	20	X	
1BLN20012	7.00	18	X	X
1BLN20013	8.00	17	X	
1BLN20014	9.00	15	X	X

[a] X indicates which stations were available for that year.

Calibration temperature profile predictions for all stations compared favorably with the observed data. Initially, inflow temperature boundary conditions were set to the observed Glen Lyn station temperature values. Because this station was approximately 15 miles upstream of the modeled boundary segment, the most upstream temperatures were being overpredicted. To improve the upstream temperature predictions, inflow temperature boundary conditions were set to observed values at the most upstream station (1BLN20014). These values were more realistic to use as boundary conditions and helped to improve temperature predictions in the upper reaches.

Although DO was modeled in a simplified manner, calibration results compared favorably with observed data (Figure 4). Since there were no observed inflow DO data available at the Glen Lyn station, DO boundary conditions were initially assumed to be saturated. Using saturated DO boundary conditions resulted in overprediction of the most upstream DO. DO boundary conditions were then set to the observed values at the most upstream station (1BLN20014). Initial DO predictions in the upper reaches were improved, which improved DO predictions in the downstream reaches as well.

Further calibration of DO required adjustments to the SOD and WCOD rates. Initially, they were set to values recommended in the CE-QUAL-W2 user's manual (Environmental Laboratory and Hydraulics Laboratory 1986). The SOD and WCOD rates were not varied longitudinally, but were set the same for all segments. After adjusting the SOD and WCOD parameters, DO profiles were improved at some stations, but were worse at others. Since there are many factors (i.e., inflow, allochthonous inputs, algal photosynthesis and respiration, and wind) influencing DO concentrations throughout a reservoir (Cole and Hannan 1990), it was decided that SOD and WCOD rates should be varied longitudinally. DO profile predictions were then significantly improved throughout the reservoir. Final SOD and WCOD rates are shown in Appendix A.

Many of the disparities between predicted DO and observed (especially in the epilimnion on 25 July 1981 and 25 August 1981, at stations 1BLN20002, 1BLN20007, 1BLN20008, and 1BLN20003) were attributed to algal production, which was not simulated by CE-QUAL-W2 during this phase of the study. Since DO was supersaturated, the higher DO values observed in the epilimnion could not be predicted without the inclusion of algae as a modeled constituent.

Assessment of model performance for release conditions was conducted by comparing predicted release conditions to observed conditions at a station 500 ft downstream of the dam. Release temperature for both years compared favorably with predicted values; however, predicted release DO was considerably lower than observed values. This was probably due in part to reaeration and the inability to predict the higher DO values in the epilimnion caused by algal production.

Verification

During verification, inflow temperature and DO boundary conditions were set using the same procedure for calibration. All other parameters (e.g., Chezy coefficient and wind sheltering coefficient) were also set the same as during calibration (Appendix A). This included having to restrict selective withdrawal at the same elevation to correctly predict the thermocline. If restricting the selective withdrawal had only been necessary for 1 year, then doing this would have been suspect; but having to do this for both years indicated that something is influencing the temperature profiles in this region of the reservoir.

Although not conclusive, this would indicate that if the withdrawal zone was not being restricted, anoxia would not be so prevalent in this zone. Consequently, the system would be flushed out with such a short residence time.

Results for verification are shown in Figure 5. Six observed temperature and DO profile data stations were available in 1983 for comparison of predicted values (Figure 5). Verification results are plotted the same as calibration. Each set of plots has, for each observed Julian day, DO profiles plotted first beginning with the most upstream station proceeding in the downstream direction with the temperature profiles plotted next in the same order. For example, in Figure 5, for the first observed Julian day, the order of the DO profile stations is 1BLN20014, 1BLN20012, 1BLN20010, 1BLN20003, 1BLN20008, and 1BLN20002. The temperature profiles for the same day follow.

An acceptable water balance was obtained for verification. The predicted WSEL was well within 0.5 m tolerance considered acceptable (Figure 6).

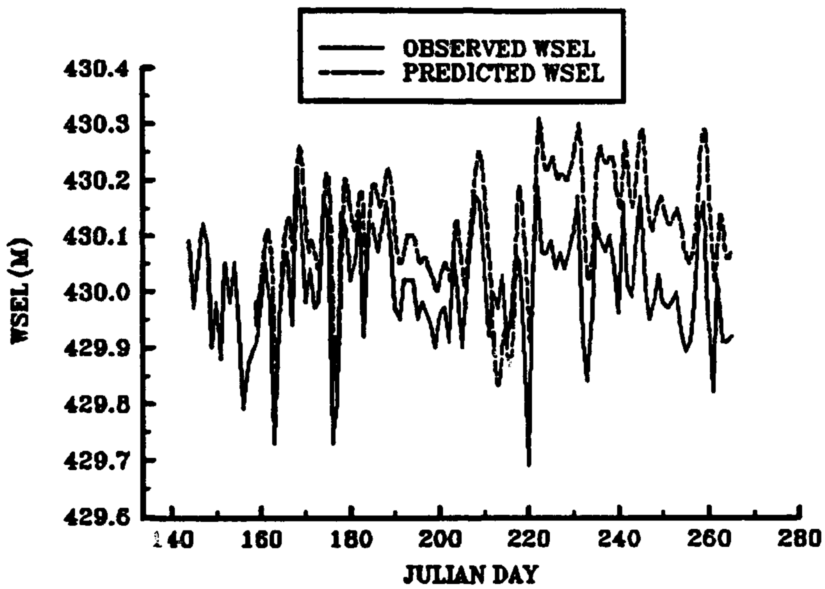

Figure 6. Predicted versus observed WSEL for 1983

Verification temperature and DO profile predictions for all stations also compared favorably with the observed data (Figure 5). As in the case of calibration, many of the disparities between predicted and observed DO in the epilimnion (i.e., on 3 August 1983, at stations 1BLN20002, 1BLN20008, 1BLN20003, and 1BLN20010) were attributed to algal production. Since sources of DO other than reaeration were not being modeled, the higher DO values observed in the epilimnion could not be predicted. On 22 September 1983, DO predictions (Figure 5) indicate overturn has occurred for most of the reservoir except at station 1BLN20002; however, this was not indicated by

observed profile data. The exact date of overturn is difficult to predict because of limitations in meteorological data (i.e., met stations may be quite a distance from the project). As a result, predicted overturn is often a few days off from observed.

Sensitivity Analyses

Sensitivity analyses were performed on the SOD and WCOD rates to assess the uncertainty of these parameters on results and conclusions. SOD and WCOD rates were increased and decreased 50 percent using the calibration/verification control data files. Comparisons were made between calibration/verification results (Figures 4 and 5) and results from the sensitivity analyses (Figures B1-B8).

Increasing and decreasing the SOD rate for both years (Figures B1 and B2 for 1981 and Figures B5 and B6 for 1983) showed very little change in the predicted DO when compared with calibration/verification results. This was also seen in the release DO results (Figures B9 and B10). The SOD results overlay the calibration and verification results. Since the SOD only affects the DO concentrations at the sediment-water interface, these results are reasonable.

Adjustments to WCOD rates for both years affected DO more than adjustments to the SOD rates as demonstrated in Figures B3 and B4 for 1981, and Figures B7 and B8 for 1983. When WCOD rates were increased for both years, the DO values in the entire water column were decreased vertically as well as longitudinally. Increasing WCOD rates caused release DO values to be less than calibration/verification release (Figures B9 and B10). When WCOD rates were decreased (Figures B4 and B8) for both years, DO values in the entire water column were increased vertically and longitudinally. This caused the release DO values to be higher in comparison to calibration/verification release results (Figures B9 and B10).

Results from the sensitivity analyses showed that DO in the model is most sensitive to values specified for WCOD.

4 Scenario Results

Changes in in-pool and release conditions were assessed by comparing scenario results to calibration and verification results. Two proposed modifications to the Bluestone project were simulated. Scenario 1 (Figure C1) consisted of raising the pool 11 ft. Scenario 2 consisted of raising the pool 11 ft as well as adding hydropower (Figure C2). For all runs, no reaeration through the sluice gates or penstocks was assumed to occur. In Scenario 1, the discharge, location, and dimensions of the intake structure were assumed to be the same as in calibration/verification runs. In Scenario 2, the discharge remained the same as the other runs, but the location and dimensions of the intake structure were changed to conform with the proposed project plans for Bluestone hydropower. Selective withdrawal remained restricted during the scenario runs since calibration/verification runs indicated this was necessary to simulate the system. If selective withdrawal was not being restricted, Scenario 2 results may be slightly different since the penstock location is deeper in the reservoir than the sluice gates. This should cause DO release concentrations to be lower than calibration/verification results.

Comparisons of release temperature and DO between calibration (1981), Scenario 1, and Scenario 2 are presented in Figure C3. Differences between calibration release results and Scenario 1 and Scenario 2 release results are shown in Figure C4. In Figure C4, differences were calculated as calibration temperature or DO minus Scenario 1 temperature or DO (represented by the dotted line), and as calibration temperature or DO minus Scenario 2 temperature or DO (represented by the dashed line). Similar comparison plots and difference plots for the verification year (1983) are shown in Figures C5 and C6, respectively.

Temperature profile results from Scenario 1 for both years (Figure C1) demonstrate that raising the pool 11 ft causes the thermocline to be shifted deeper in the reservoir. This causes the release temperatures for both years to be, on the average, cooler than calibration/verification results until around Julian day 220 (Figures C4 and C6). Although the thermocline is deeper in the reservoir than during calibration and verification, with the higher pool, it is at a higher elevation in relation to the outlet resulting in cooler water being withdrawn. After Julian day 220, temperature releases were, on the average, warmer (maximum difference 1.1 °C) than calibration/verification results. This

was especially true for the dry year (1981). Comparison of release temperatures in Figures C3 and C5 shows that adding hydropower had very little effect on release temperature results. The mean release temperatures for the calibration, Scenario 1, and Scenario 2 simulations using 1981 input data were 24.92, 25.01, and 25.03 °C, respectively, and the mean release temperatures for the verification, Scenario 1, and Scenario 2 simulations using 1983 input data were 25.02, 24.86, and 24.84 °C, respectively.

DO profiles for both years (Figure C1) for Scenario 1 show that because of the deeper thermocline, higher DO values occur deeper in the reservoir. This is also seen in Scenario 2 results (Figure C2). Differences in DO results shown in Figures C4 and C6 indicate that, on the average, lower DO values (maximum difference approximately 5 mg/ℓ for 1981 and 3 mg/ℓ for 1983) were released for both scenarios in comparison with calibration/verification releases. The mean release DO concentrations for calibration, Scenario 1, and Scenario 2 simulations for 1981 were 5.43, 4.82, and 4.87 mg/ℓ, respectively, and the mean release DO concentrations for verification, Scenario 1, and Scenario 2 simulations for 1983 were 5.88, 5.42, and 5.42 mg/ℓ, respectively. Lower DO values were due to more of the hypolimnetic DO being available for withdrawal. The greatest DO difference between the two scenarios (Figures C4 and C6) occurs between Julian day 255 and day 265 for both years. This difference may have resulted from the timing of overturn and the difference in the withdrawal zone caused by the different intake locations and dimensions.

5 Summary and Conclusions

CE-QUAL-W2 was applied to Bluestone Lake, WV, to evaluate impacts to in-pool and release temperature and DO. The model was calibrated and verified for a dry and wet year (1981 and 1983, respectively). After calibration/verification, sensitivity analyses were performed on the SOD and WCOD rates. Two scenario runs were simulated looking at (a) raising the pool 11 ft and (b) raising the pool 11 ft and adding hydropower.

Raising the pool 11 ft and adding hydropower caused changes in both in-pool and release temperature and DO when compared with calibration and verification results. From the two scenarios simulated, the following conclusions were derived:

a. Temperature profiles for most stations (especially stations closer to the dam) showed deeper thermoclines resulting in higher DO values deeper in the reservoir. Release temperatures increased as much as 1.1 °C. Most of the higher release temperatures occurred during the latter half of the simulation for both years. Average release temperatures for the simulation period were similar in value between calibration/verification and the scenario results.

b. The average decrease in DO releases was approximately 0.6 mg/ℓ for both years. Decreases in release DO occurred throughout the simulation period.

c. The addition of hydropower (Scenario 2 Figure C2) did not significantly affect temperature and DO results when compared with Scenario 1 results (Figure C1). Selective withdrawal was restricted for these runs since this was necessary to calibrate and verify the model. Late in the study, Scenario 2 was rerun for both years with selective withdrawal not being restricted. In these runs, temperature profile results for both years showed very little thermal stratification. In addition, DO profile concentrations were also higher and deeper in the reservoir, and the mean release DO concentrations were about the same as Scenario 2 results. The plots from these runs have not been included in the report, but can be obtained upon request.

References

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Davis, J. E., Holland, J. P., Schneider, M. L., and Wilhelms, S. C. (1987). "SELECT: A numerical, one-dimensional model for selective withdrawal," Instructional Report E-87-2, U.S. Army Engineer Waterways Experiment Station, Vicksburg, MS.

Environmental and Hydraulics Laboratories. (1986). "CE-QUAL-W2: A numerical two-dimensional, laterally averaged model of hydrodynamics and water quality; User's manual," Instruction Report E-86-5, U.S. Army Engineer Waterways Experiment Station, Vicksburg. MS.

Appendix A CE-QUAL-W2 Control Data Files

```
Bluestone Reservoir Control File for CE-QUAL-W2

TITLE C ..............................TITLE....................................
        Bluestone Reservoir calibration - run 24
        Adjusted inflow temperatures & DO concentrations
        Hyd - CHEZY = 50.0, WSC  = 0.7, KBSW = 28, dltf = 0.5
        WQ  - SOD   =  variable, WCOD = variable

TIME CON  TMSTRT   TMEND    YEAR
          180.85  265.85    1981

DLT CON      NDT  MINDLT
               1     1.0

DLT DATE    DLTD    DLTD    DLTD    DLTD    DLTD    DLTD    DLTD    DLTD    DLTD
             0.0

DLT MAX   DLTMAX  DLTMAX  DLTMAX  DLTMAX  DLTMAX  DLTMAX  DLTMAX  DLTMAX  DLTMAX
          3600.0

DLT FRN     DLTF    DLTF    DLTF    DLTF    DLTF    DLTF    DLTF    DLTF    DLTF
            0.50

SURFACE       KT   DATUM
              15   417.3

BRANCH G      US      DS     UHS     DHS    PHIO
Br 1           2      31       0       0   3.142
Br 2          34      37       0      29   3.142

LOCATION     LAT    LONG
            37.6    80.9

INIT CND     IT2  IICETH   WTYPE
            -1.0     0.0   FRESH

CALCULAT     VBC     MBC     PQC    PQTC     EVC     PRC
             OFF     OFF     OFF     OFF     OFF     OFF

INTERPOL   INFIC    TRIC   DTRIC    HDIC   OUTIC    WDIC   METIC
              ON     OFF     OFF     OFF      ON     OFF      ON

DEAD SEA   WINDC    QINC   QOUTC   HEATC
              ON      ON      ON      ON

ICE COVER   ICEC   SLICE  SLHTEX  ALBEDO     HWI   BETAI  GAMMAI  ICEMIN   ICET2
             OFF  DETAIL    TERM    0.25    10.0     0.6    0.07    0.05     4.0

TRANSPORT  SLTRC   THETA
        QUICKEST    0.00

WSC NUMB    NWSC
               1

WSC DATE    WSCD    WSCD    WSCD    WSCD    WSCD    WSCD    WSCD    WSCD    WSCD
           0.000

WSC COEF     WSC     WSC     WSC     WSC     WSC     WSC     WSC     WSC     WSC
            0.70
```

HYD COEF	AX	IDX	AZMIN	DZMIN	DZMAX	CHEZY			
	1.0	1.0	1.4E-6	1.4E-7	1000.0	50.0			
SEL WITH	SWC	SWC	SWC	SWC	SWC	SWC	SWC	SWC	SWC
	ON	OFF							
N STRUC	NSTR	NTSR	NSTR	NSTR	NSTR	NSTR	NSTR	NSTR	NSTR
	1	1							
K BOTTOM	KBSW	KBSW	KBSW	KBSW	KBSW	KBSW	KBSW	KBSW	KBSW
	28								
SINK TYPE	SINK	SINK	SINK	SINK	SINK	SINK	SINK	SINK	SINK
Br 1	LINE								
Br 2									
E STRUC	ESTR	ESTR	ESTR	ESTR	ESTR	ESTR	ESTR	ESTR	ESTR
Br 1	426.5								
Br 2									
W STRUC	WSTR	WSTR	WSTR	WSTR	WSTR	WSTR	WSTR	WSTR	WSTR
Br 1	240.85								
Br 2									
N OUTLET	NOUT	NOUT	NOUT	NOUT	NOUT	NOUT	NOUT	NOUT	NOUT
O LAYER	KOUT	KOUT	KOUT	KOUT	KOUT	KOUT	KOUT	KOUT	KOUT
Br 1									
Br 2									
N WDRWAL	NWD								
	0								
W SEGMNT	IWD	IWD	IWD	IWD	IWD	IWD	IWD	IWD	IWD
	0								
W LAYER	KWD	KWD	KWD	KWD	KWD	KWD	KWD	KWD	KWD
	0								
N TRIBS	NTR								
	0								
TRIB SEG	ITR	ITR	ITR	ITR	ITR	ITR	ITR	ITR	ITR
	29								
DST TRIB	DTRC	DTRC	DTRC	DTRC	DTRC	DTRC	DTRC	DTRC	DTRC
	OFF	OFF							
SNAPSHOT	FORM	UPRNC	WPRNC	TPRNC					
	LONG	OFF	OFF	ON					
SHRT SEG	IPRSF	IPRSF	IPRSF	IPRSF	IPRSF	IPRSF	IPRSF	IPRSF	IPRSF
	2	5	10	15	20	25	30	31	35
	36	37							
LONG SEG	IPRLF	IPRLF	IPRLF	IPRLF	IPRLF	IPRLF	IPRLF	IPRLF	IPRLF
	2	4	6	8	10	12	15	17	18
	20	22	25	26	28	29	30	31	

```
SNP PRNT    SNPC    NSNP
              ON       4

SNP DATE    SNPD    SNPD    SNPD    SNPD    SNPD    SNPD    SNPD    SNPD    SNPD
          180.85  208.85  236.85  265.85

SNP FREQ    SNPF    SNPF    SNPF    SNPF    SNPF    SNPF    SNPF    SNPF    SNPF
           100.0     2.0     2.0   100.0

PRF PLOT    PRFC    NPRF   NIPRF
              ON       4      10

PRF DATE    PRFD    PRFD    PRFD    PRFD    PRFD    PRFD    PRFD    PRFD    PRFD
          180.85  208.85  236.85  265.85

PRF FREQ    PRFF    PRFF    PRFF    PRFF    PRFF    PRFF    PRFF    PRFF    PRFF
           100.0   100.0   100.0   100.0

PRF SEG     IPRF    IPRF    IPRF    IPRF    IPRF    IPRF    IPRF    IPRF    IPRF
              15      17      18      20      22      25      26      28      29
              31

TSR PLOT    TSRC    NTSR
              ON       1

TSR DATE    TSRD    TSRD    TSRD    TSRD    TSRD    TSRD    TSRD    TSRD    TSRD
           181.5

TSR FREQ    TSRF    TSRF    TSRF    TSRF    TSRF    TSRF    TSRF    TSRF    TSRF
            0.25

VPL PLOT    VPLC    NVPL
             OFF       4

VPL DATE    VPLD    VPLD    VPLD    VPLD    VPLD    VPLD    VPLD    VPLD    VPLD
          181.85  209.85  237.85  266.85

VPL FREQ    VPLF    VPLF    VPLF    VPLF    VPLF    VPLF    VPLF    VPLF    VPLF
           100.0   100.0   100.0   100.0

CPL PLOT    CPLC    NCPL
             OFF       1

CPL DATE    CPLD    CPLD    CPLD    CPLD    CPLD    CPLD    CPLD    CPLD    CPLD
         212.208

CPL FREQ    CPLF    CPLF    CPLF    CPLF    CPLF    CPLF    CPLF    CPLF    CPLF
             1.0

RESTART     RSOC    NRSO    RSIC
             OFF       1     OFF

RSO DATE    RSOD    RSOD    RSOD    RSOD    RSOD    RSOD    RSOD    RSOD    RSOD
          267.85

RSO FREQ    RSOF    RSOF    RSOF    RSOF    RSOF    RSOF    RSOF    RSOF    RSOF
           100.0

CST COMP  CCOMPC    LIMC     SDC  FREQUK
              ON     OFF      ON       1
```

```
CST ACT      ACC     ACC     ACC     ACC     ACC     ACC     ACC     ACC     ACC
             OFF     OFF     OFF     OFF     OFF     OFF     OFF     OFF     OFF
             OFF     OFF     ON      OFF     OFF     OFF     OFF     OFF     OFF
             OFF     OFF

CST ICON     CIC     CIC     CIC     CIC     CIC     CIC     CIC     CIC     CIC
             0.0     0.0     0.0     0.0     0.0     0.0     0.0     0.0     0.0
             0.0     0.0    -2.0     0.0     0.0     0.0     0.0     0.0     0.0
             0.0     0.0

CST PRNT   CPRNC   CPRNC   CPRNC   CPRNC   CPRNC   CPRNC   CPRNC   CPRNC   CPRNC
             OFF     OFF     OFF     OFF     OFF     OFF     OFF     OFF     OFF
             OFF     OFF     ON      OFF     OFF     OFF     OFF     OFF     OFF
             OFF     OFF

CIN CON    INACC   INACC   INACC   INACC   INACC   INACC   INACC   INACC   INACC
              ON     OFF     OFF     OFF     OFF     OFF     OFF     OFF     OFF
             OFF     OFF      ON     OFF     OFF     OFF     OFF     OFF     OFF
             OFF     OFF

CTR CON    TRACC   TRACC   TRACC   TRACC   TRACC   TRACC   TRACC   TRACC   TRACC
             OFF     OFF     OFF      ON     OFF     OFF     OFF     OFF     OFF
             OFF     OFF     OFF     OFF     OFF     OFF     OFF     OFF     OFF
             OFF     OFF

CDT CON    DTACC   DTACC   DTACC   DTACC   DTACC   DTACC   DTACC   DTACC   DTACC
             OFF     OFF     OFF     OFF     OFF     OFF     OFF     OFF     OFF
             OFF     OFF     OFF     OFF     OFF     OFF     OFF     OFF     OFF
             OFF     OFF

CPR CON    PRACC   PRACC   PRACC   PRACC   PRACC   PRACC   PRACC   PRACC   PRACC
             OFF     OFF     OFF     OFF     OFF     OFF     OFF     OFF     OFF
             OFF     OFF     OFF     OFF     OFF     OFF     OFF     OFF     OFF
             OFF     OFF

EX COEF    EXH2O  EXINOR   EXORG    BETA
            0.45    0.01     0.3    0.45

COLIFORM  COLQ10   COLDK
            1.04     1.4

S SOLIDS   SSETL
             2.0

ALGAE      AGROW   AMORT   AEXCR   ARESP   ASETL  ASATUR  ALGDET
             1.5    0.05    0.02    0.02    0.14    50.0    0.80

ALG RATE    AGT1    AGT2    AGT3    AGT4    AGK1    AGK2    AGK3    AGK4
            10.0    30.0    35.0    40.0     0.1    0.98    0.98     0.1

DISS ORG   LABDK   LRFDK   REFDK
            0.12   0.001   0.001

DETRITUS   DETDK   DSETL
            0.08    0.35

ORG RATE    OMT1    OMT2    OMK1    OMK2
             4.0    20.0     0.1    0.98
```

```
SEDIMENT     SEDDK
              0.10

S DEMAND       SOD      SOD      SOD      SOD      SOD      SOD      SOD      SOD      SOD
             0.050    0.050    0.050     0.10    0.150     0.20    0.250    0.250    0.250
             0.250     0.30    0.350    0.350    0.350    0.350    0.350    0.350     0.30
             0.250    0.250    0.250    0.250    0.250     0.20     0.20     0.20     0.20
             0.150     0.20     0.20     0.20     0.20     0.20     0.20    0.150    0.150
              0.10    0.050

WCOD TEMP    TWCOD
            1.0147

WC DEMAND     WCOD     WCOD     WCOD     WCOD     WCOD     WCOD     WCOD     WCOD     WCOD
              0.70     0.70     0.70     0.70     0.70     0.70     0.70     0.70     0.70
              0.70     0.70     0.70     0.70     0.70     0.70     0.70     0.70     0.50
              0.50     0.50     0.50     0.50     0.50     0.40     0.30     0.30     0.30
              0.30     0.30     0.30     0.30     0.30     0.30     0.30     0.30     0.30
              0.30     0.30

CBOD          KBOD     TBOD     RBOD
              0.25   1.0147     1.85

PHOSPHOR    PO4REL    PARTP     AHSP
             0.015      1.2    0.009

AMMONIA     NH3REL    NH3DK    PARTN     AHSN
              0.08     0.12      1.0    0.014

NH3 RATE     NH3T1    NH3T2    NH3K1    NH3K2
               5.0     20.0      0.1     0.98

NITRATE      NO3DK
              0.12

NO3 RATE     NO3T1    NO3T2    NO3K1    NO3K2
               5.0     20.0      0.1     0.98

SED CO2     CO2REL
               0.1

IRON         FEREL   FESETL
               0.5      2.0

STOICHMT     O2NH3    O2ORG   O2RESP    O2ALG     BIOP     BION     BIOC
              4.57      1.4      1.1      1.4    0.011     0.08     0.45

O2 LIMIT     O2LIM
              0.00

BTH FILE..............................BTHFN.................................
        bth.npt

VPR FILE..............................VPRFN.................................
        vpr.npt

LPR FILE..............................LPRFN.................................
        lpr.npt

RSI FILE..............................RSIFN.................................
```

```
        rsi.npt

MET FILE..............................METFN...................................
        met.npt

QWD FILE..............................QWDFN...................................
        not used

QIN FILE..............................QINFN...................................
Br 1    qin_br1.npt
Br 1    qin_br2.npt

TIN FILE..............................TINFN...................................
Br 1    tin_br1.npt
Br 1    tin_br2.npt

CIN FILE..............................CINFN...................................
Br 1    cin_br1.npt
Br 1    cin_br2.npt

QOT FILE..............................QOTFN...................................
Br 1    qot_br1.npt
Br 1    qot_br2.npt

QTR FILE..............................QTRFN...................................
Tr 1    qtr_tr1.npt

TTR FILE..............................TTRFN...................................
Tr 1    ttr_tr1.npt

CTR FILE..............................CTRFN...................................
Tr 1    ctr_tr1.npt

QDT FILE..............................QDTFN...................................
Br 1    not used
Br 1    not used

TDT FILE..............................TDTFN...................................
Br 1    not used
Br 1    not used

CDT FILE..............................CDTFN...................................
Br 1    not used
Br 1    not used

PRE FILE..............................PREFN...................................
Br 1    not used
Br 1    not used

TPR FILE..............................TPRFN...................................
Br 1    not used
Br 1    not used

CPR FILE..............................CPRFN...................................
Br 1    not used
Br 1    not used

EUH FILE..............................EUHFN...................................
Br 1    not used
Br 1    not used
```

```
TUH FILE.................................TUHFN..................................
Br 1     not used
Br 1     not used

CUH FILE.................................CUHFN..................................
Br 1     not used
Br 1     not used

EDH FILE.................................EDHFN..................................
Br 1     not used
Br 1     not used

TDH FILE.................................TDHFN..................................
Br 1     not used
Br 1     not used

CDH FILE.................................CDHFN..................................
Br 1     not used
Br 1     not used

SNP FILE.................................SNPFN..................................
         snp_run28.opt

TSR FILE.................................TSRFN..................................
         tsr_run28.opt

PRF FILE.................................PRFFN..................................
         prf_run28.opt

VPL FILE.................................VPLFN..................................
         vpl.opt

CPL FILE.................................CPLFN..................................
         cpl.opt
```

```
                     Bluestone Reservoir Control File for CE-QUAL-W2

TITLE C ..............................TITLE..................................
        Bluestone Reservoir 1983 verification - run 25
        Adjusted water surface, inflow temperatures, & DO concentrations
        Hyd - CHEZY = 50.0, WSC  = 0.7, KBSW = 28, dltf = 0.9
        WQ  - SOD   =  variable, WCOD = variable

TIME CON  TMSTRT   TMEND    YEAR
           158.8  264.85    1983

DLT CON      NDT  MINDLT
               1     1.0

DLT DATE    DLTD    DLTD    DLTD    DLTD    DLTD    DLTD    DLTD    DLTD    DLTD
             0.0

DLT MAX   DLTMAX  DLTMAX  DLTMAX  DLTMAX  DLTMAX  DLTMAX  DLTMAX  DLTMAX  DLTMAX
          3600.0

DLT FRN     DLTF    DLTF    DLTF    DLTF    DLTF    DLTF    DLTF    DLTF    DLTF
            0.90

SURFACE       KT   DATUM
              15  417.30

BRANCH G      US      DS     UHS     DHS    PHIO
Br 1           2      31       0       0   3.142
Br 2          34      37       0      29   3.142

LOCATION     LAT    LONG
            37.6    80.9

INIT CND     IT2  IICETH   WTYPE
            -1.0     0.0   FRESH

CALCULAT     VBC     MBC     PQC    PQTC     EVC     PRC
             OFF     OFF     OFF     OFF     OFF     OFF

INTERPOL   INFIC    TRIC   DTRIC    HDIC   OUTIC    WDIC   METIC
              ON     OFF     OFF     OFF      ON     OFF      ON

DEAD SEA   WINDC    QINC   QOUTC   HEATC
              ON      ON      ON      ON

ICE COVER   ICEC   SLICE  SLHTEX  ALBEDO     HWI   BETAI  GAMMAI  ICEMIN   ICET2
             OFF  DETAIL    TERM    0.25    10.0     0.6    0.07    0.05     4.0

TRANSPORT  SLTRC   THETA
        QUICKEST    0.00

WSC NUMB    NWSC
               1

WSC DATE    WSCD    WSCD    WSCD    WSCD    WSCD    WSCD    WSCD    WSCD    WSCD
           0.000

WSC COEF     WSC     WSC     WSC     WSC     WSC     WSC     WSC     WSC     WSC
            0.70
```

```
HYD COEF        AX     IDX   AZMIN   DZMIN   DZMAX   CHEZY
               1.0     1.0  1.4E-6  1.4E-7  1000.0    50.0

SEL WITH       SWC     SWC     SWC     SWC     SWC     SWC     SWC     SWC     SWC
                ON     OFF

N STRUC       NSTR    NTSR    NSTR    NSTR    NSTR    NSTR    NSTR    NSTR    NSTR
                 1       1

K BOTTOM      KBSW    KBSW    KBSW    KBSW    KBSW    KBSW    KBSW    KBSW    KBSW
                28

SINK TYPE     SINK    SINK    SINK    SINK    SINK    SINK    SINK    SINK    SINK
Br 1          LINE
Br 2

E STRUC       ESTR    ESTR    ESTR    ESTR    ESTR    ESTR    ESTR    ESTR    ESTR
Br 1         426.5
Br 2

W STRUC       WSTR    WSTR    WSTR    WSTR    WSTR    WSTR    WSTR    WSTR    WSTR
Br 1        240.85
Br 2

N OUTLET      NOUT    NOUT    NOUT    NOUT    NOUT    NOUT    NOUT    NOUT    NOUT

O LAYER       KOUT    KOUT    KOUT    KOUT    KOUT    KOUT    KOUT    KOUT    KOUT
Br 1
Br 2

N WDRWAL       NWD
                 0

W SEGMNT       IWD     IWD     IWD     IWD     IWD     IWD     IWD     IWD     IWD
                 0

W LAYER        KWD     KWD     KWD     KWD     KWD     KWD     KWD     KWD     KWD
                 0

N TRIBS        NTR
                 0

TRIB SEG       ITR     ITR     ITR     ITR     ITR     ITR     ITR     ITR     ITR
                29

DST TRIB      DTRC    DTRC    DTRC    DTRC    DTRC    DTRC    DTRC    DTRC    DTRC
               OFF     OFF

SNAPSHOT      FORM   UPRNC   WPRNC   TPRNC
              LONG     OFF     OFF      ON

SHRT SEG     IPRSF   IPRSF   IPRSF   IPRSF   IPRSF   IPRSF   IPRSF   IPRSF   IPRSF
                 2       5      10      15      20      25      30      31      35
                36      37

LONG SEG     IPRLF   IPRLF   IPRLF   IPRLF   IPRLF   IPRLF   IPRLF   IPRLF   IPRLF
                 2       4       6       8      10      12      15      17      18
                20      22      25      26      28      29      30      31
```

```
SNP PRNT     SNPC     NSNP
               ON        7

SNP DATE     SNPD     SNPD     SNPD     SNPD     SNPD     SNPD     SNPD     SNPD     SNPD
           144.80   158.80   172.80   200.80   214.80   228.80   264.80   284.80

SNP FREQ     SNPF     SNPF     SNPF     SNPF     SNPF     SNPF     SNPF     SNPF     SNPF
            100.0    100.0    100.0    100.0    100.0    100.0    100.0    100.0

PRF PLOT     PRFC     NPRF    NIPRF
               ON        7        6

PRF DATE     PRFD     PRFD     PRFD     PRFD     PRFD     PRFD     PRFD     PRFD     PRFD
            158.8    172.8    200.8    214.8    228.8    264.8    284.8

PRF FREQ     PRFF     PRFF     PRFF     PRFF     PRFF     PRFF     PRFF     PRFF     PRFF
            100.0    100.0    100.0    100.0    100.0    100.0    100.0

PRF SEG      IPRF     IPRF     IPRF     IPRF     IPRF     IPRF     IPRF     IPRF     IPRF
               15       18       22       26       28       31

TSR PLOT     TSRC     NTSR
               ON        1

TSR DATE     TSRD     TSRD     TSRD     TSRD     TSRD     TSRD     TSRD     TSRD     TSRD
            144.5

TSR FREQ     TSRF     TSRF     TSRF     TSRF     TSRF     TSRF     TSRF     TSRF     TSRF
             0.25

VPL PLOT     VPLC     NVPL
              OFF        7

VPL DATE     VPLD     VPLD     VPLD     VPLD     VPLD     VPLD     VPLD     VPLD     VPLD
            144.5    158.5    172.5    200.5    214.5    228.5    264.5    284.5

VPL FREQ     VPLF     VPLF     VPLF     VPLF     VPLF     VPLF     VPLF     VPLF     VPLF
            100.0    100.0    100.0    100.0    100.0    100.0    100.0    100.0

CPL PLOT     CPLC     NCPL
              OFF        1

CPL DATE     CPLD     CPLD     CPLD     CPLD     CPLD     CPLD     CPLD     CPLD     CPLD
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CPL FREQ     CPLF     CPLF     CPLF     CPLF     CPLF     CPLF     CPLF     CPLF     CPLF
              1.0

RESTART      RSOC     NRSO     RSIC
              OFF        1      OFF

RSO DATE     RSOD     RSOD     RSOD     RSOD     RSOD     RSOD     RSOD     RSOD     RSOD
            172.5

RSO FREQ     RSOF     RSOF     RSOF     RSOF     RSOF     RSOF     RSOF     RSOF     RSOF
            100.0

CST COMP   CCOMPC     LIMC      SDC   FREQUK
               ON      OFF       ON        1
```

```
CST ACT       ACC    ACC    ACC    ACC    ACC    ACC    ACC    ACC    ACC
              OFF    OFF    OFF    OFF    OFF    OFF    OFF    OFF    OFF
              OFF    OFF    ON     OFF    OFF    OFF    OFF    OFF    OFF
              OFF    OFF

CST ICON      CIC    CIC    CIC    CIC    CIC    CIC    CIC    CIC    CIC
              0.0    0.0    0.0    0.0    0.0    0.0    0.0    0.0    0.0
              0.0    0.0   -1.0    0.0    0.0    0.0    0.0    0.0    0.0
              0.0    0.0

CST PRNT    CPRNC  CPRNC  CPRNC  CPRNC  CPRNC  CPRNC  CPRNC  CPRNC  CPRNC
              OFF    OFF    OFF    OFF    OFF    OFF    OFF    OFF    OFF
              OFF    OFF    ON     OFF    OFF    OFF    OFF    OFF    OFF
              OFF    OFF

CIN CON     INACC  INACC  INACC  INACC  INACC  INACC  INACC  INACC  INACC
              OFF    OFF    OFF    OFF    OFF    OFF    OFF    OFF    OFF
              OFF    OFF    ON     OFF    OFF    OFF    OFF    OFF    OFF
              OFF    OFF

CTR CON     TRACC  TRACC  TRACC  TRACC  TRACC  TRACC  TRACC  TRACC  TRACC
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              OFF    OFF    OFF    OFF    OFF    OFF    OFF    OFF    OFF
              OFF    OFF

CDT CON     DTACC  DTACC  DTACC  DTACC  DTACC  DTACC  DTACC  DTACC  DTACC
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              OFF    OFF    OFF    OFF    OFF    OFF    OFF    OFF    OFF
              OFF    OFF

CPR CON     PRACC  PRACC  PRACC  PRACC  PRACC  PRACC  PRACC  PRACC  PRACC
              OFF    OFF    OFF    OFF    OFF    OFF    OFF    OFF    OFF
              OFF    OFF    OFF    OFF    OFF    OFF    OFF    OFF    OFF
              OFF    OFF

EX COEF     EXH2O EXINOR  EXORG   BETA
             0.45   0.01    0.3   0.45

COLIFORM   COLQ10  COLDK
             1.04    1.4

S SOLIDS    SSETL
              2.0

ALGAE       AGROW  AMORT  AEXCR  ARESP  ASETL ASATUR ALGDET
              1.5   0.05   0.02   0.02   0.14   50.0   0.80

ALG RATE     AGT1   AGT2   AGT3   AGT4   AGK1   AGK2   AGK3   AGK4
             10.0   30.0   35.0   40.0    0.1   0.98   0.98    0.1

DISS ORG    LABDK  LRFDK  REFDK
             0.12  0.001  0.001

DETRITUS    DETDK  DSETL
             0.08   0.35

ORG RATE     OMT1   OMT2   OMK1   OMK2
              4.0   20.0    0.1   0.98

SEDIMENT    SEDDK
```

```
          0.10

S DEMAND       SOD      SOD      SOD      SOD      SOD      SOD      SOD      SOD      SOD
             0.050    0.050    0.050     0.10    0.150     0.20    0.250    0.250    0.250
             0.250     0.30    0.350    0.350    0.350    0.350    0.350    0.350     0.30
             0.250    0.250    0.250    0.250    0.250     0.20     0.20     0.20     0.20
             0.150     0.20     0.20     0.20     0.20     0.20     0.20    0.150    0.150
              0.10    0.050

WCOD TEMP    TWCOD
            1.0147

WC DEMAND     WCOD     WCOD     WCOD     WCOD     WCOD     WCOD     WCOD     WCOD     WCOD
              0.70     0.70     0.70     0.70     0.70     0.70     0.70     0.70     0.70
              0.70     0.70     0.70     0.70     0.70     0.70     0.70     0.70     0.50
              0.50     0.50     0.50     0.50     0.50     0.40     0.30     0.30     0.30
              0.30     0.30     0.30     0.30     0.30     0.30     0.30     0.30     0.30
              0.30     0.30

CBOD          KBOD     TBOD     RBOD
              0.25   1.0147     1.85

PHOSPHOR    PO4REL    PARTP     AHSP
             0.015      1.2    0.009

AMMONIA     NH3REL    NH3DK    PARTN     AHSN
              0.08     0.12      1.0    0.014

NH3 RATE     NH3T1    NH3T2    NH3K1    NH3K2
               5.0     20.0      0.1     0.98

NITRATE      NO3DK
              0.12

NO3 RATE     NO3T1    NO3T2    NO3K1    NO3K2
               5.0     20.0      0.1     0.98

SED CO2     CO2REL
               0.1

IRON         FEREL   FESETL
               0.5      2.0

STOICHMT     O2NH3    O2ORG   O2RESP    O2ALG     BIOP     BION     BIOC
              4.57      1.4      1.1      1.4    0.011     0.08     0.45

O2 LIMIT     O2LIM
              0.00

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VPR FILE..............................VPRFN.................................
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RSI FILE..............................RSIFN.................................
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QOT FILE................................QOTFN...................................
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Br 2    qot_br2.npt

QTR FILE................................QTRFN...................................
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TTR FILE................................TTRFN...................................
Tr 1    ttr_tr1.npt

CTR FILE................................CTRFN...................................
Tr 1    ctr_tr1.npt

QDT FILE................................QDTFN...................................
Br 1    not used
Br 2    not used

TDT FILE................................TDTFN...................................
Br 1    not used
Br 2    not used

CDT FILE................................CDTFN...................................
Br 1    not used
Br 2    not used

PRE FILE................................PREFN...................................
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Br 2    not used

TPR FILE................................TPRFN...................................
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Br 2    not used

CPR FILE................................CPRFN...................................
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Br 2    not used

EUH FILE................................EUHFN...................................
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Br 2    not used
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Br 2     not used

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Br 2     not used

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TDH FILE................................TDHFN....................................
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Br 2     not used

CDH FILE................................CDHFN....................................
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Br 2     not used

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TSR FILE................................TSRFN....................................
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PRF FILE................................PRFFN....................................
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VPL FILE................................VPLFN....................................
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CPL FILE................................CPLFN....................................
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Appendix B
Sensitivity Analysis Results

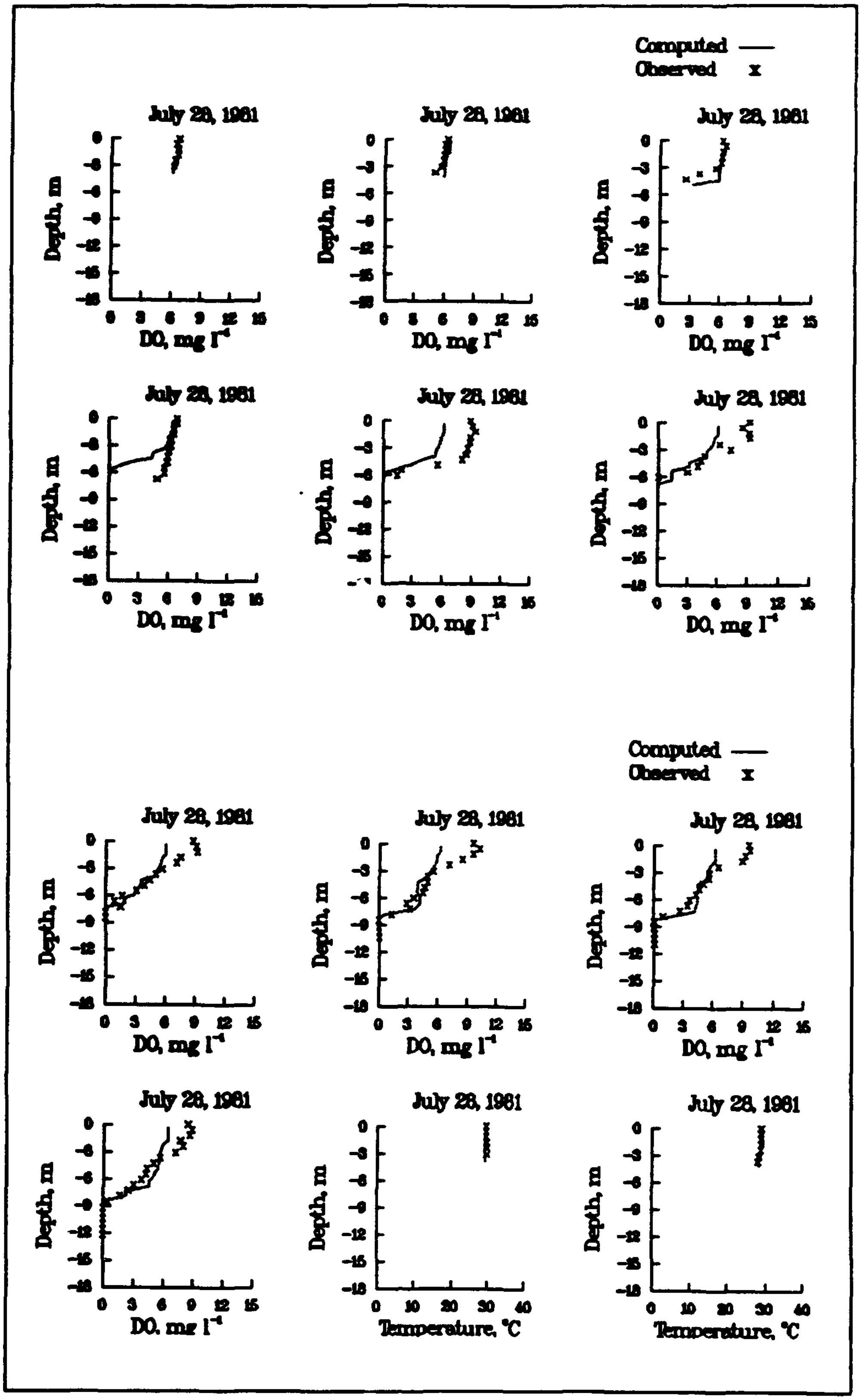


Figure B1. Sensitivity analysis results from increasing SOD parameter 50 percent for 1981 (Sheet 1 of 5)

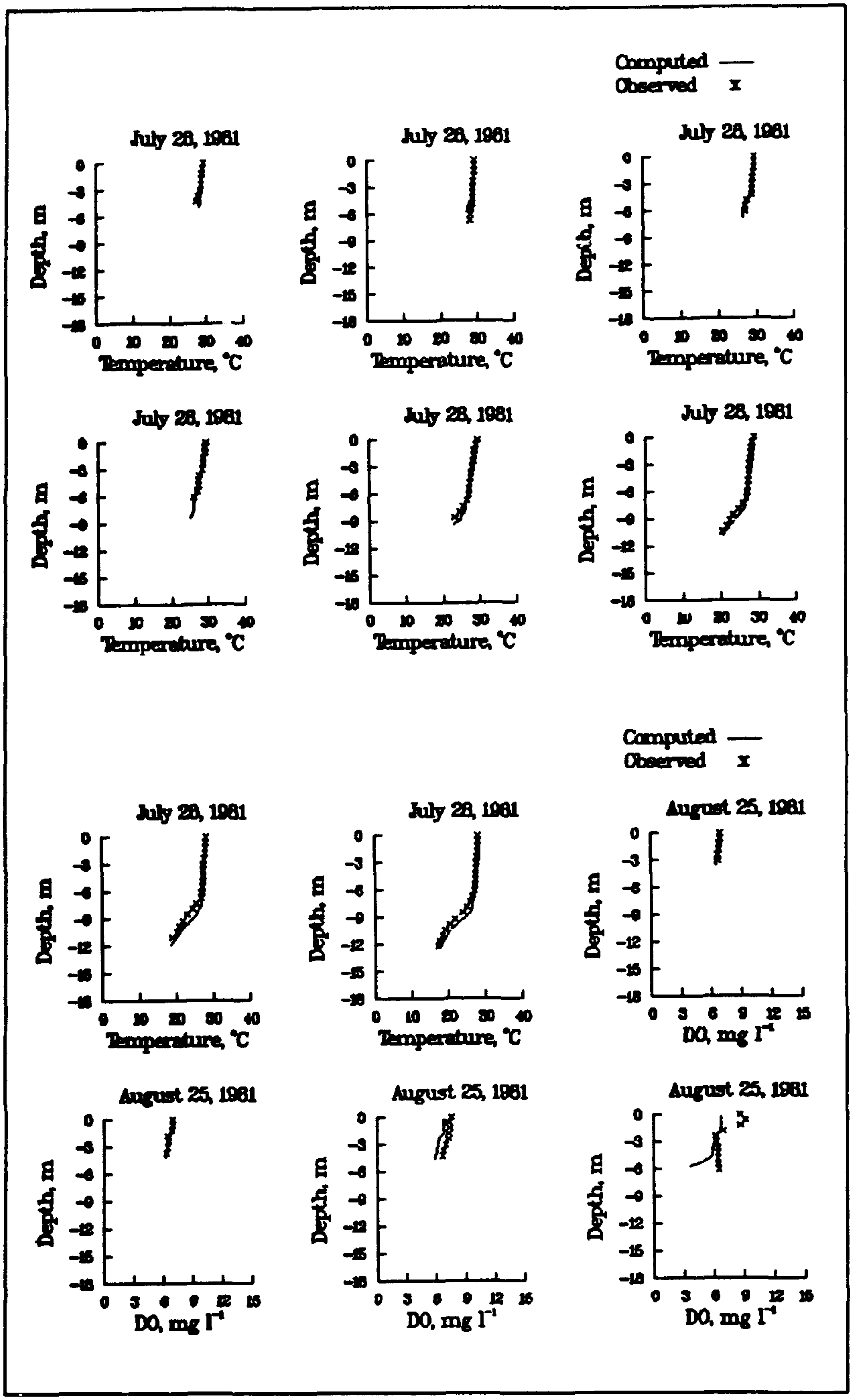


Figure B1. (Sheet 2 of 5)

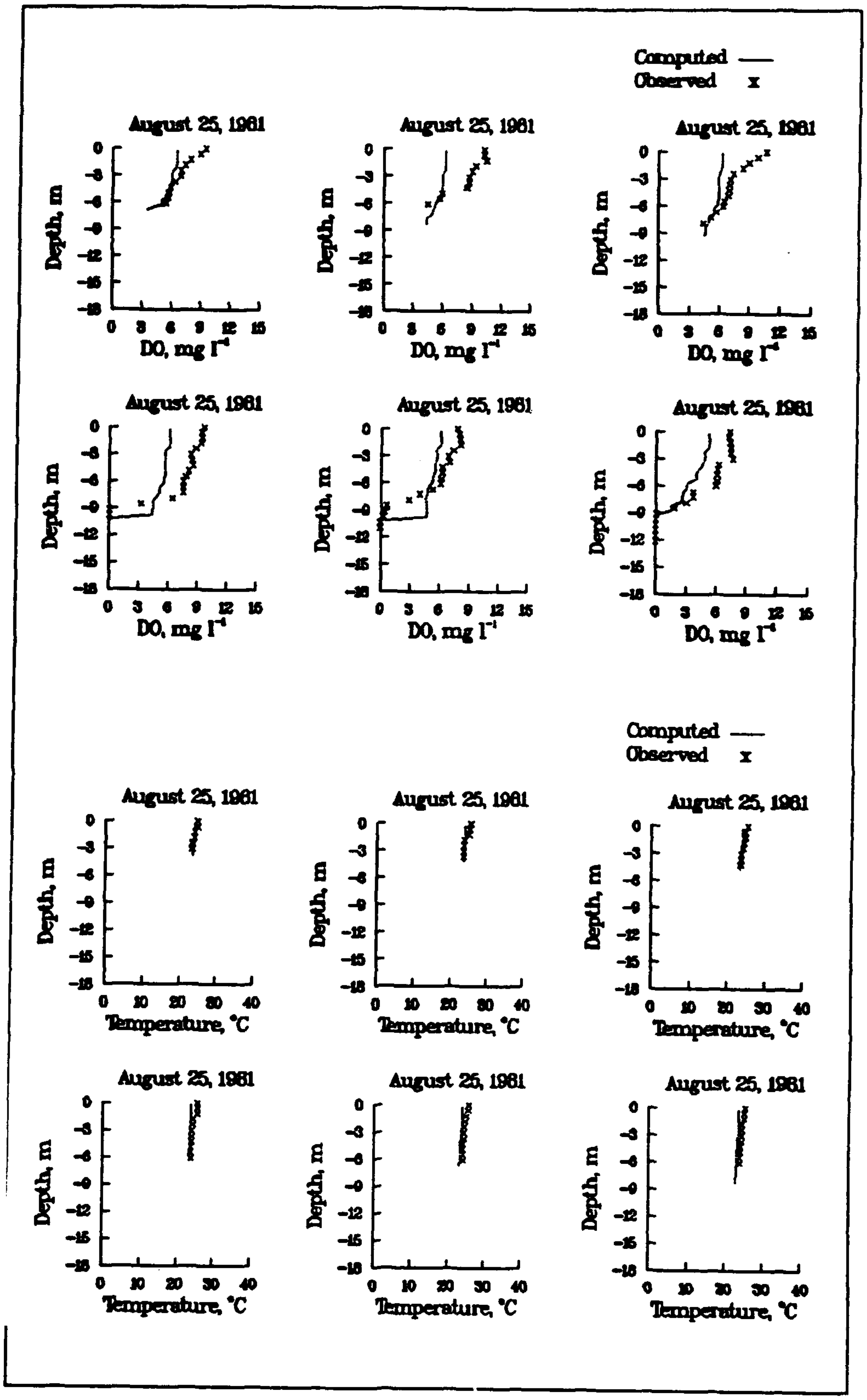


Figure B1. (Sheet 3 of 5)

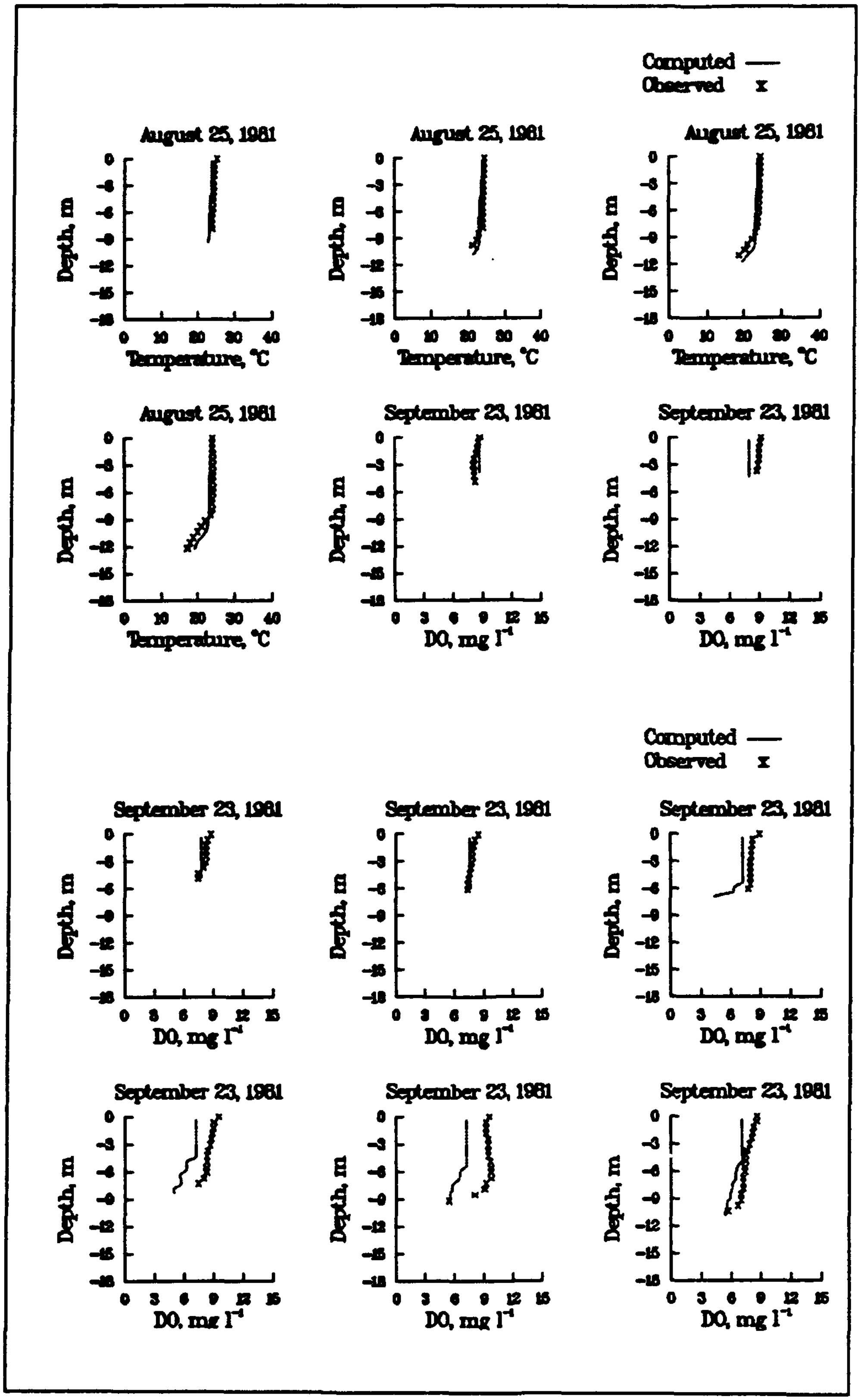


Figure B1. (Sheet 4 of 5)

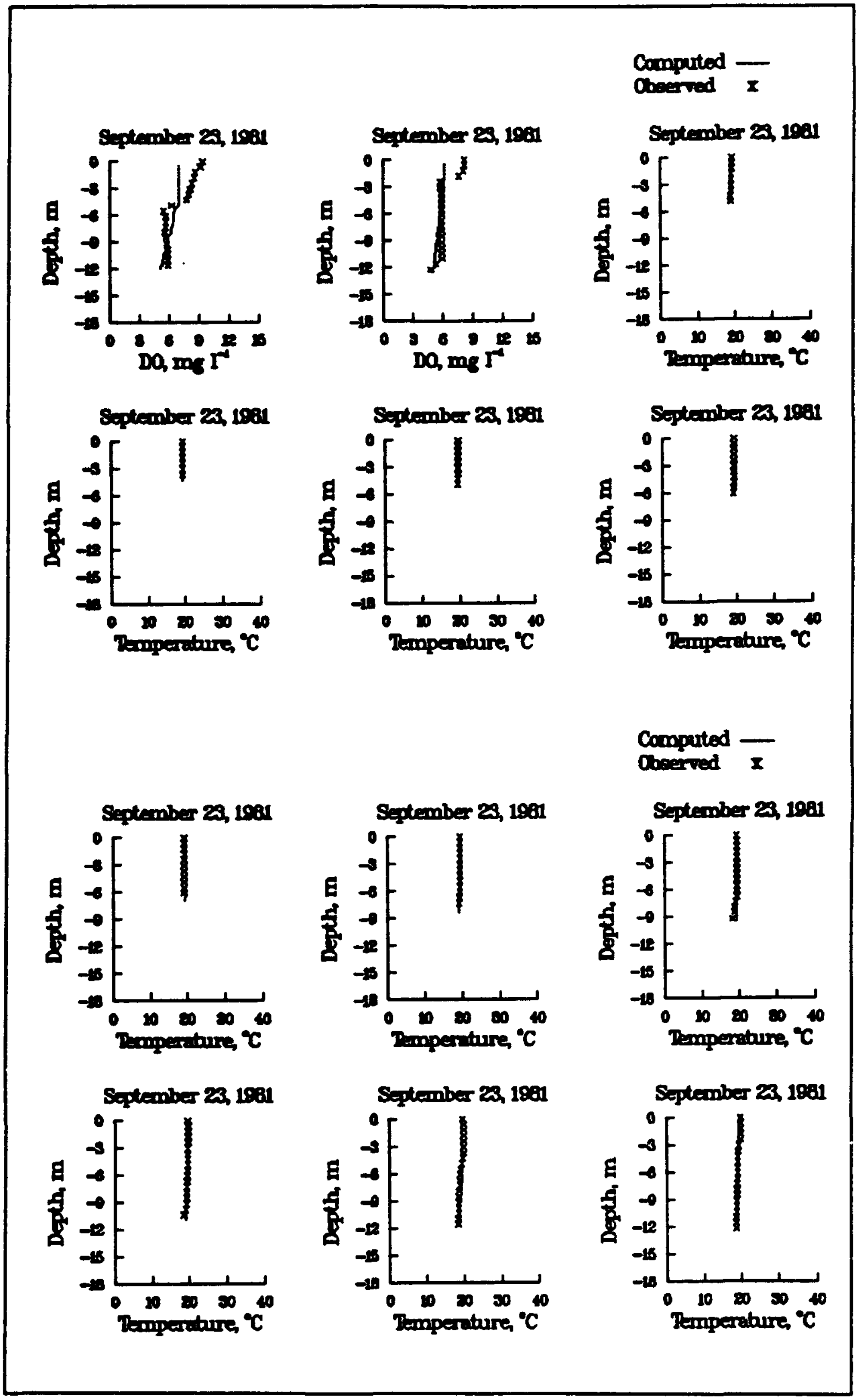


Figure B1. (Sheet 5 of 5)

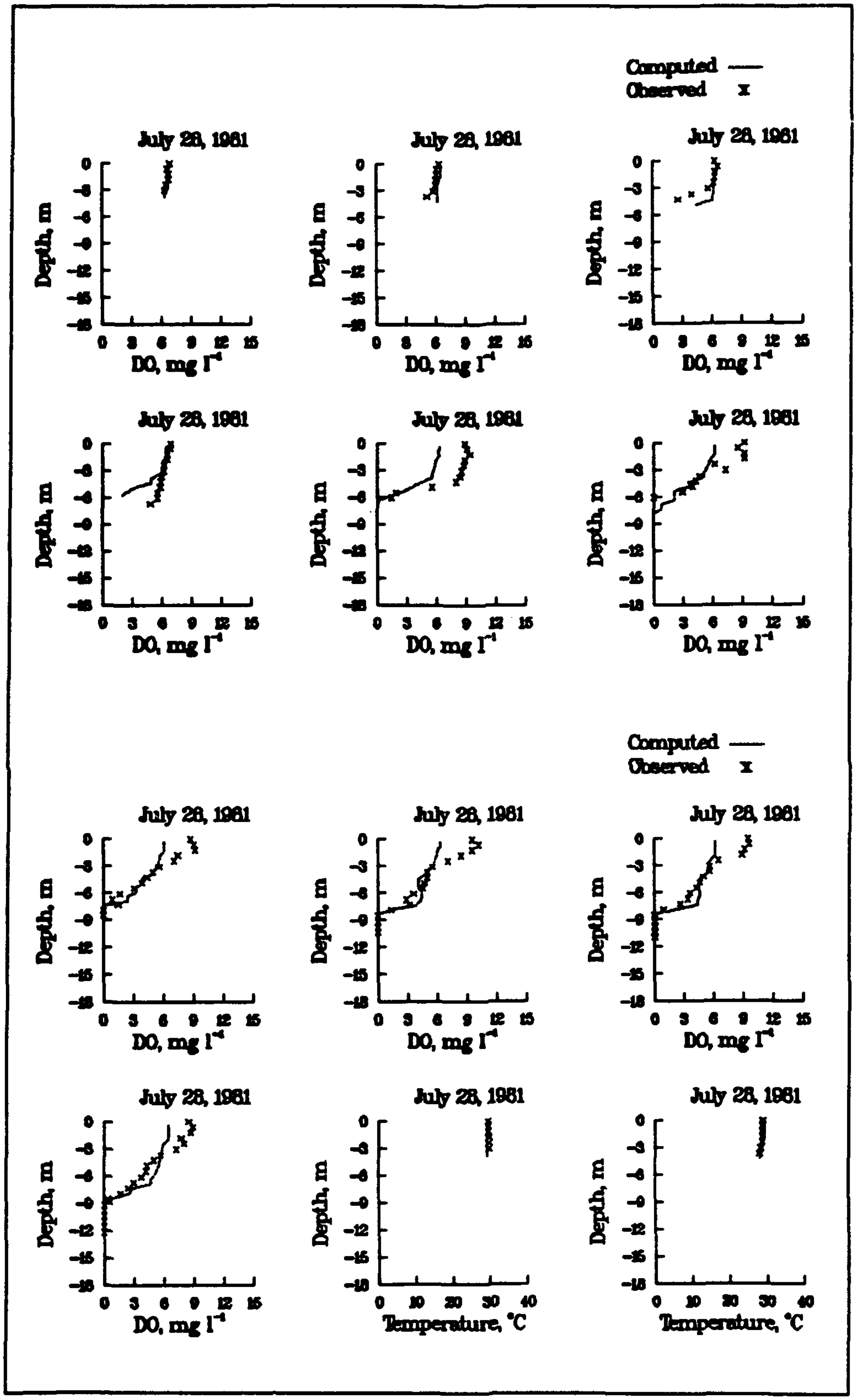


Figure B2. Sensitivity analysis results from decreasing SOD parameter 50 percent for 1981 (Sheet 1 of 5)

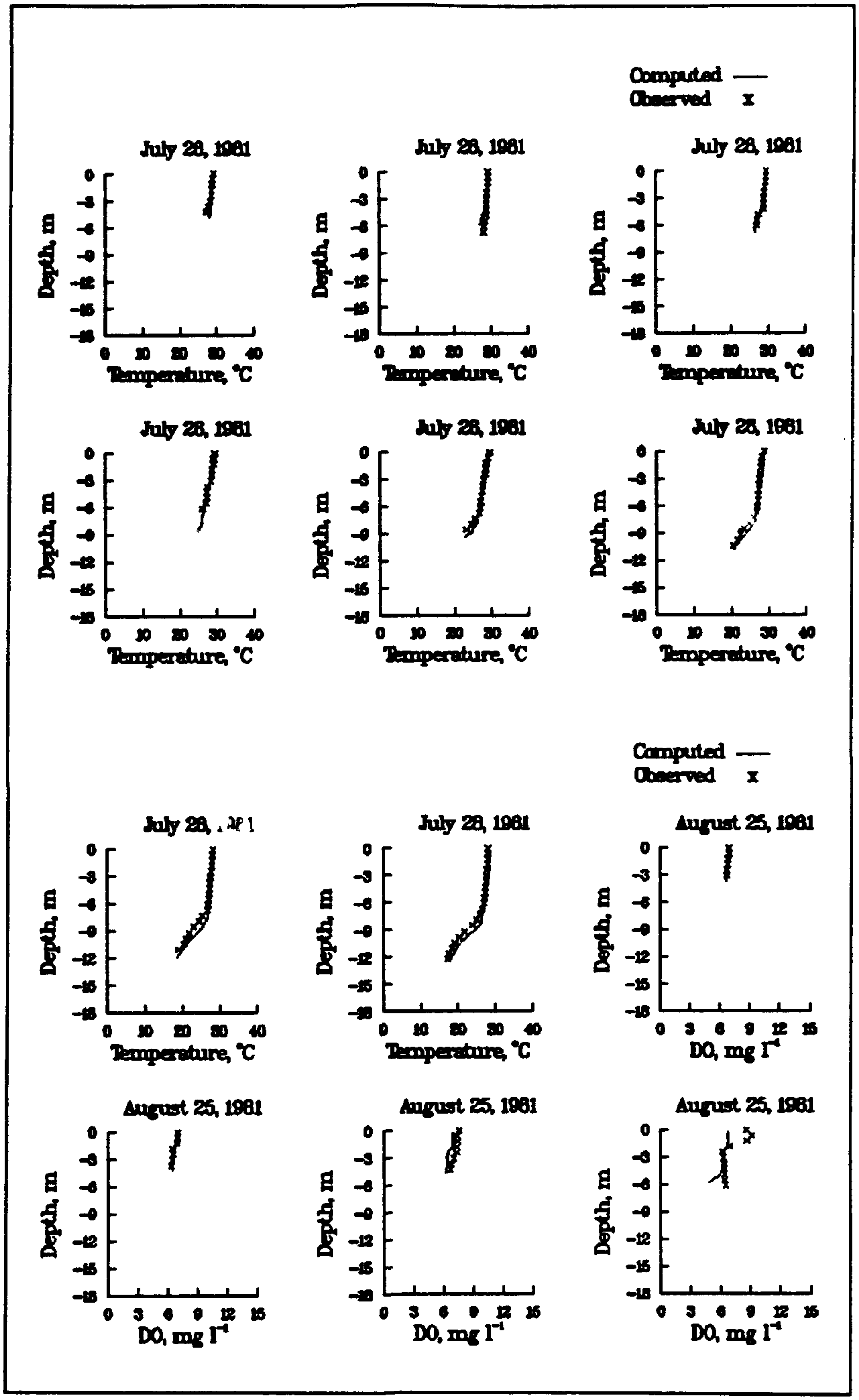


Figure B2. (Sheet 2 of 5)

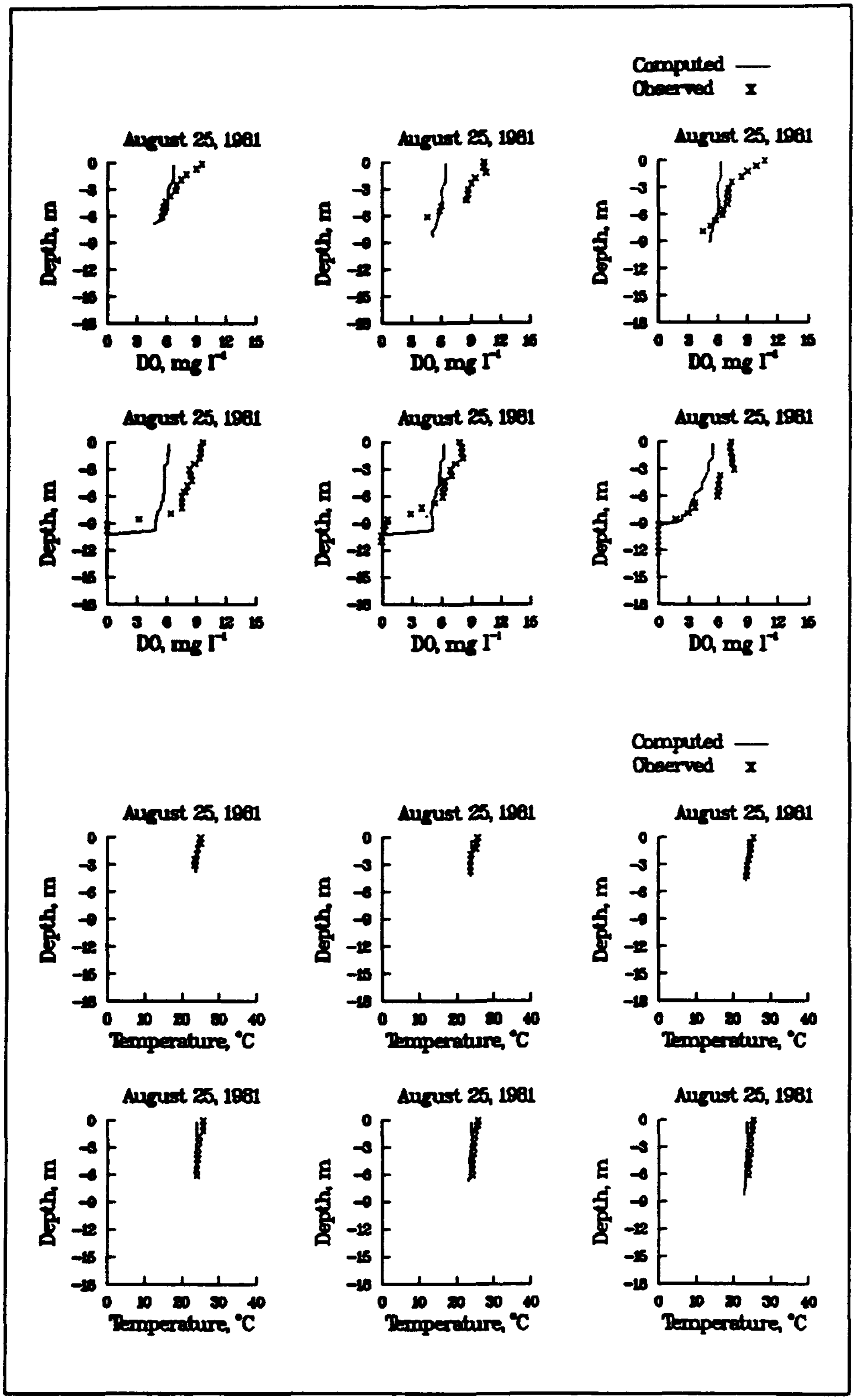


Figure B2. (Sheet 3 of 5)

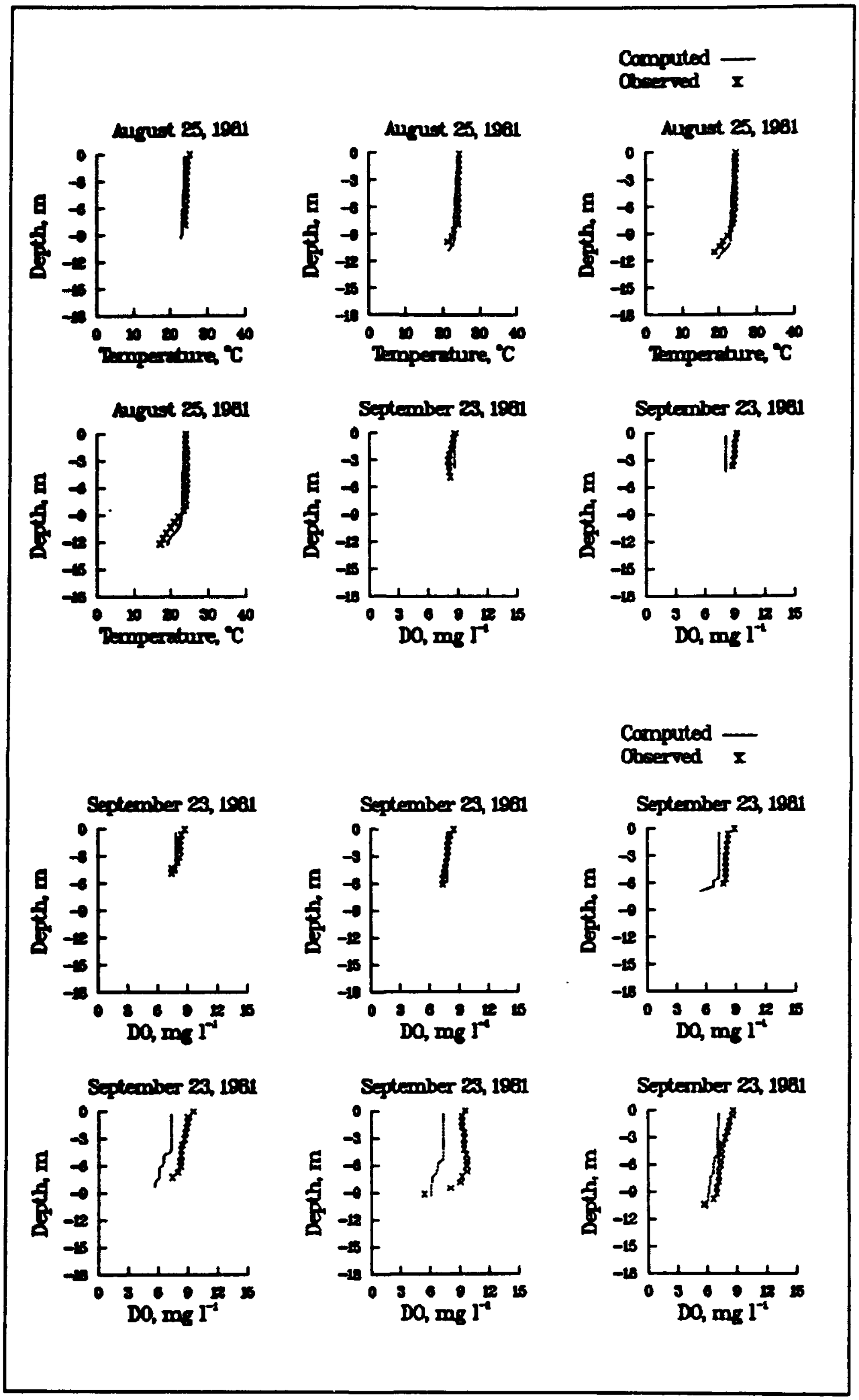


Figure B2. (Sheet 4 of 5)

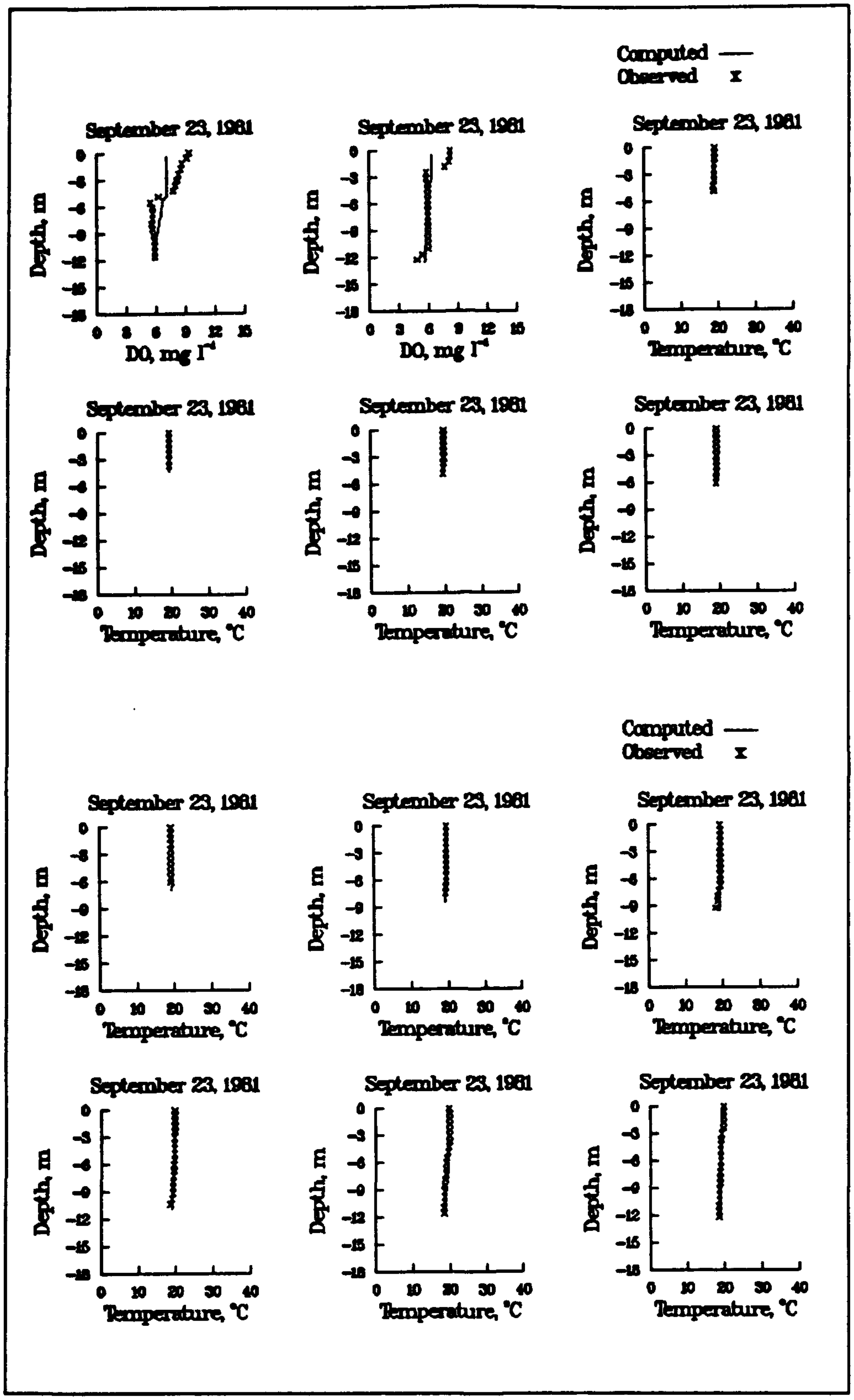


Figure B2. (Sheet 5 of 5)

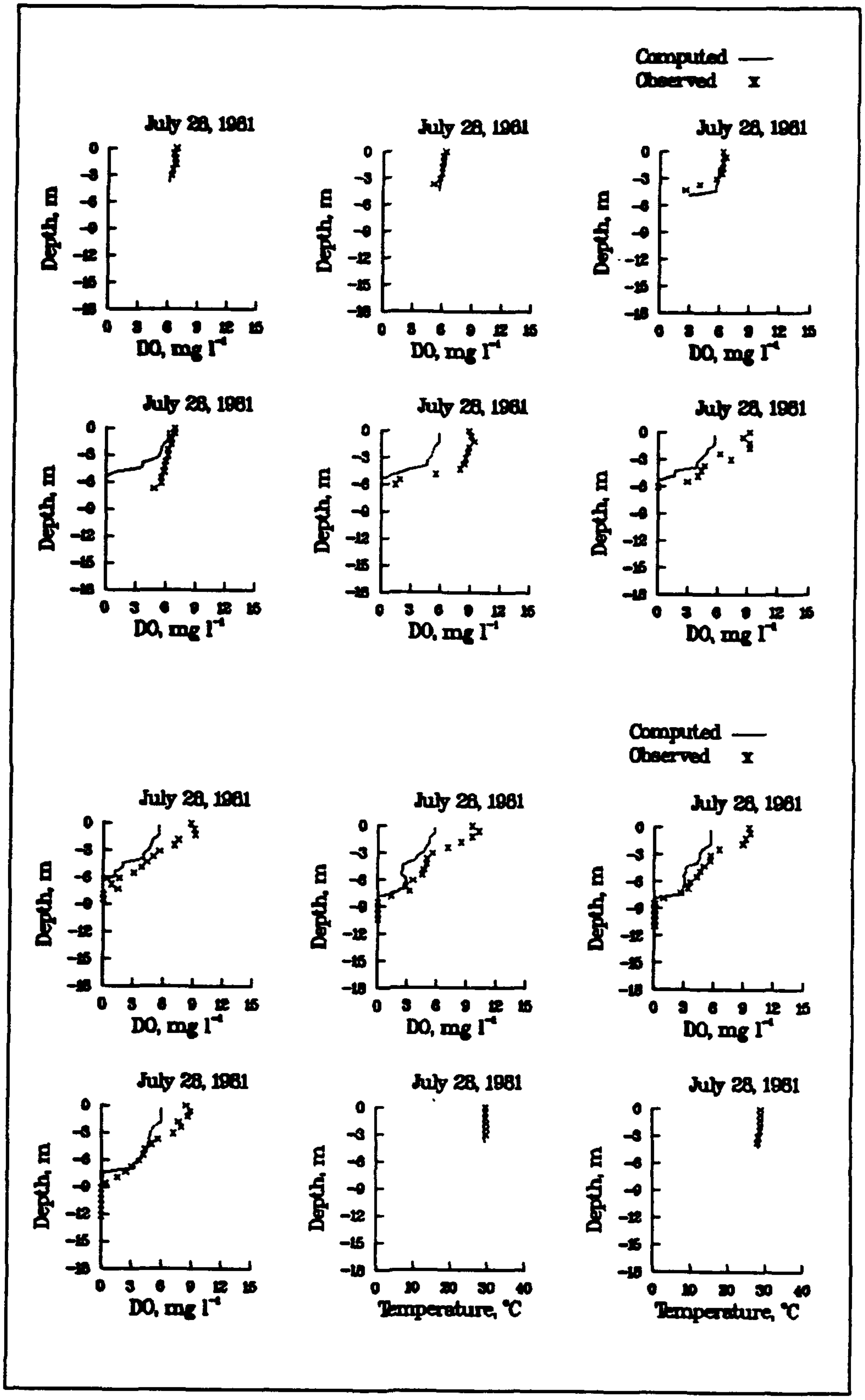


Figure B3. Sensitivity analysis results from increasing WCOD parameter 50 percent for 1981 (Sheet 1 of 5)

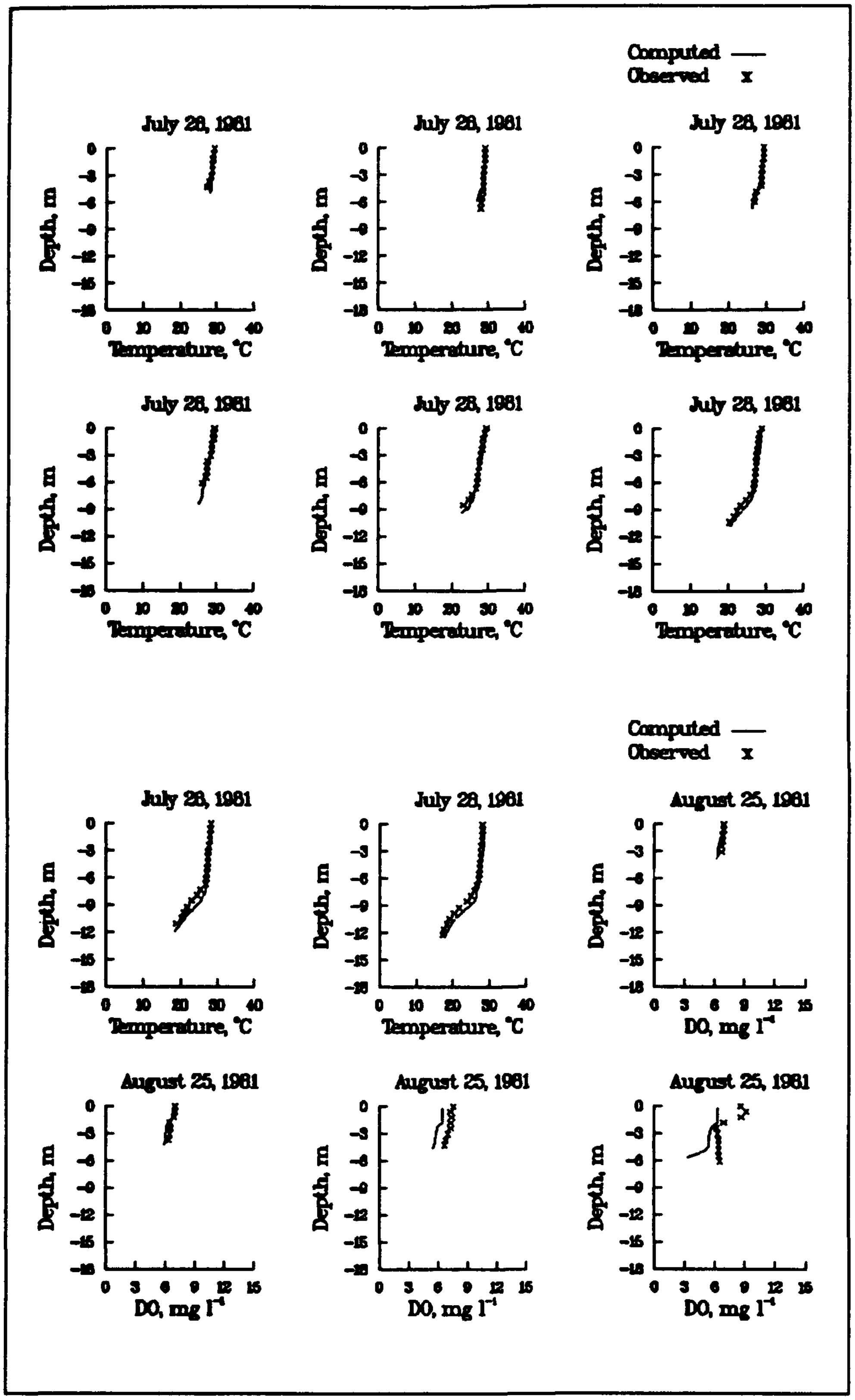


Figure B3. (Sheet 2 of 5)

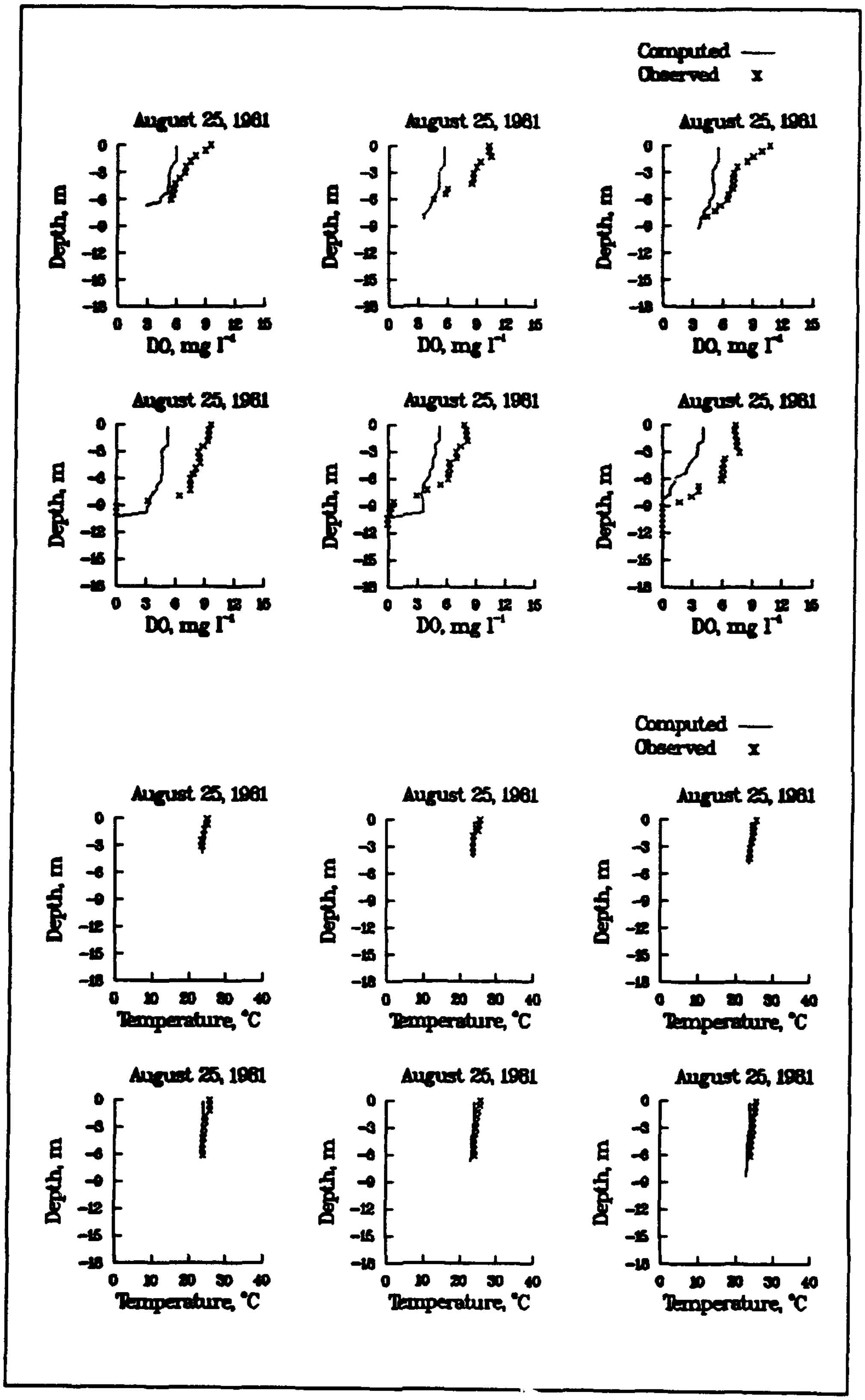


Figure B3. (Sheet 3 of 5)

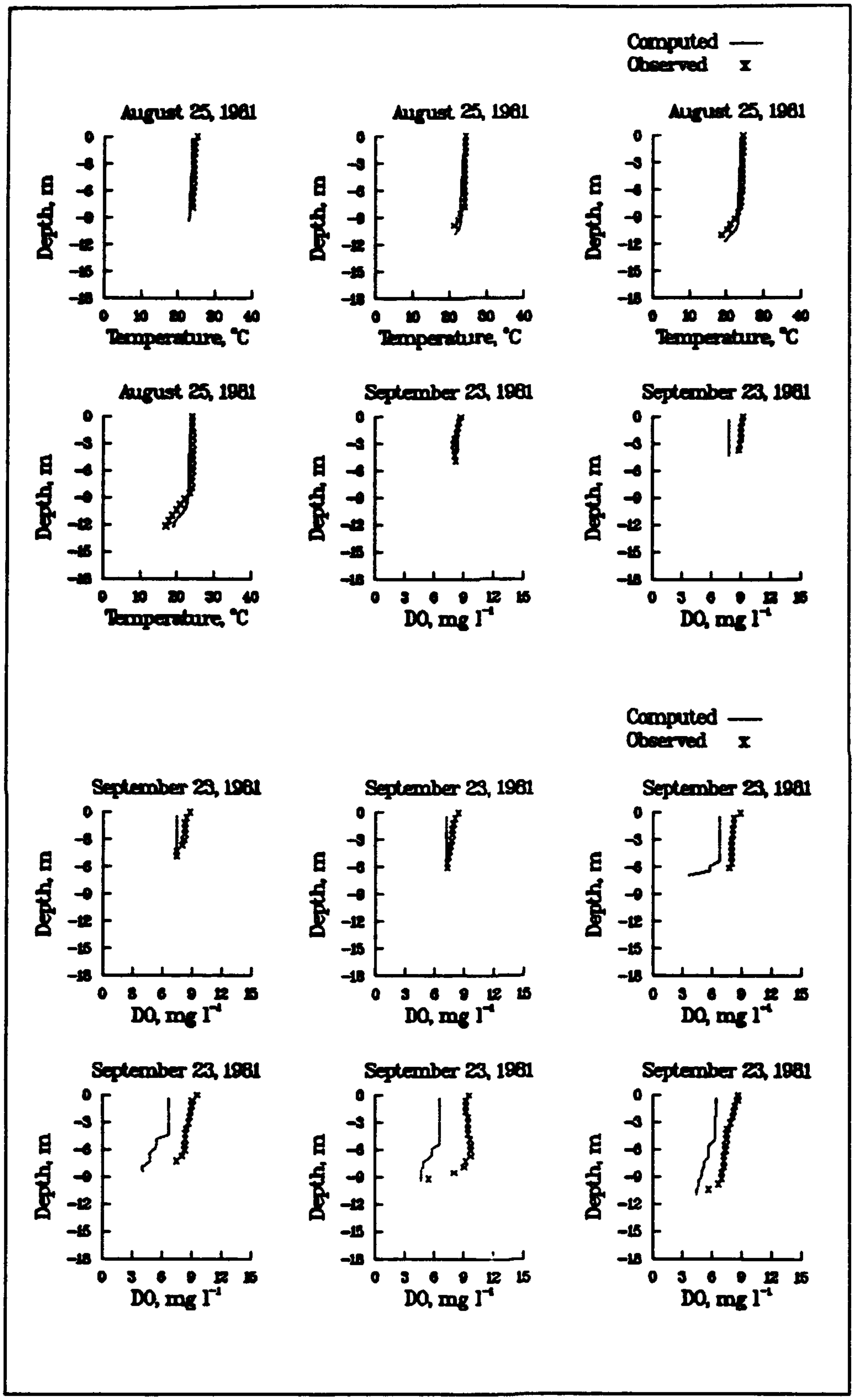


Figure B3. (Sheet 4 of 5)

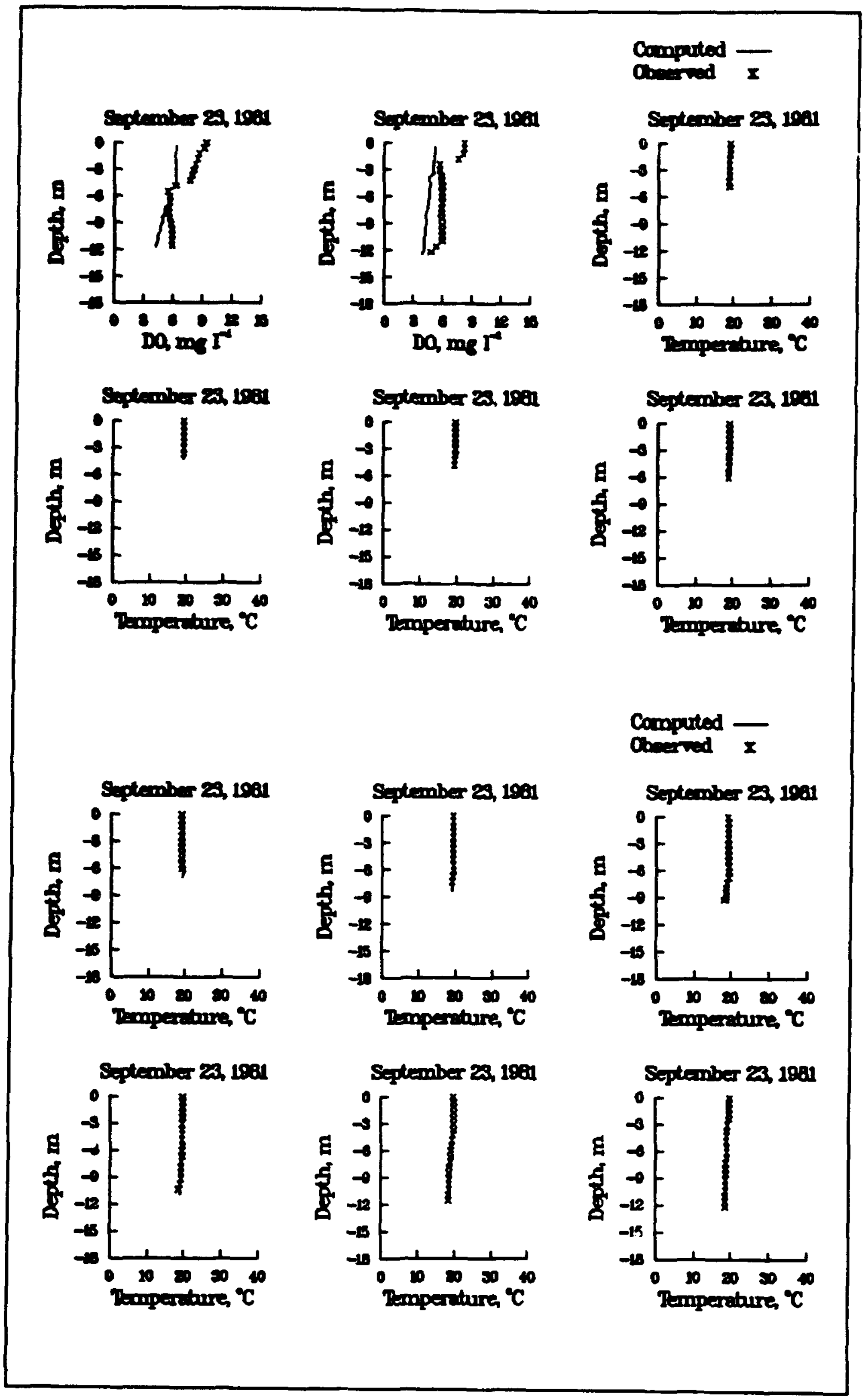


Figure B3. (Sheet 5 of 5)

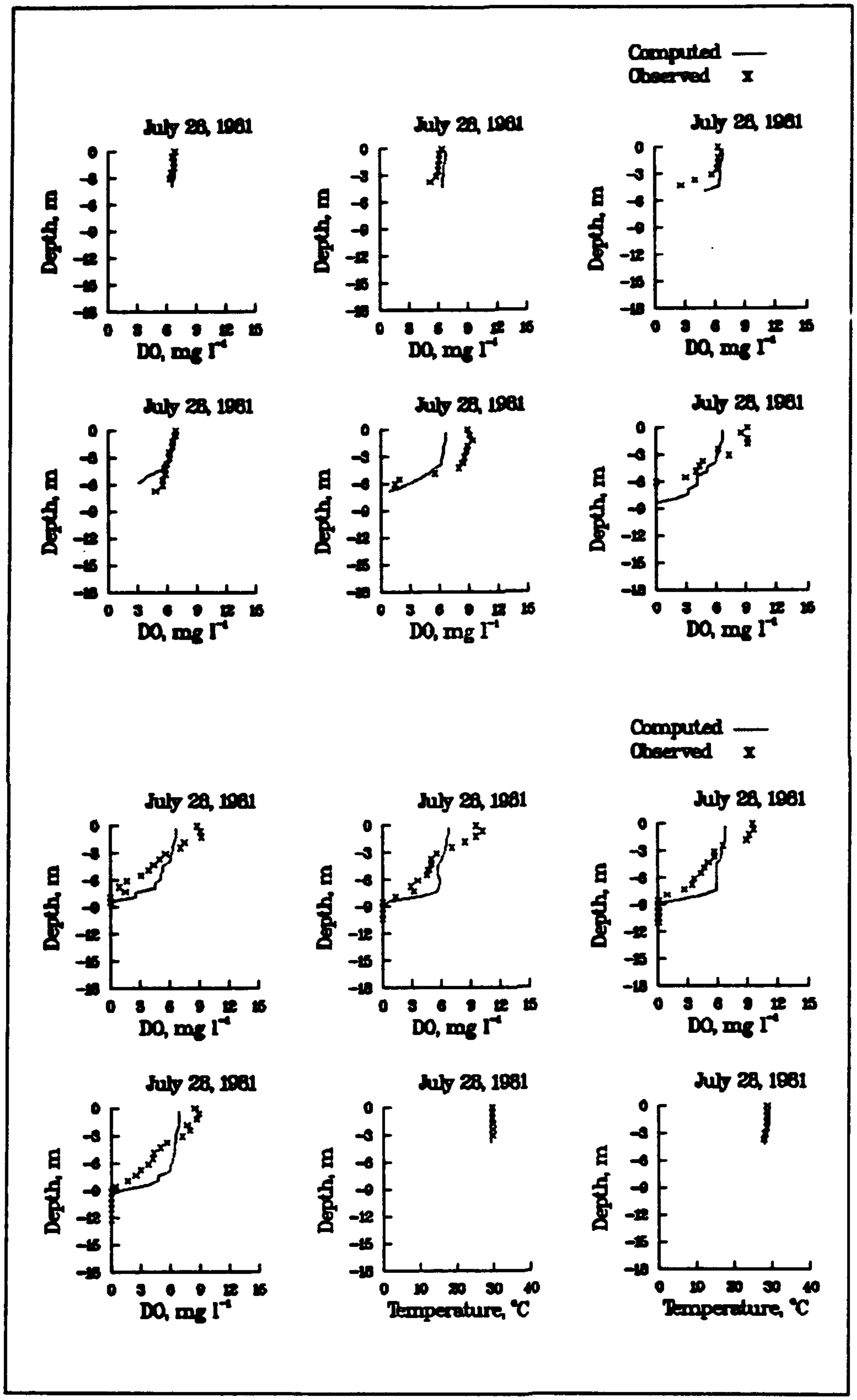


Figure B4. Sensitivity analysis results from decreasing WCOD parameter 50 percent for 1981 (Sheet 1 of 5)

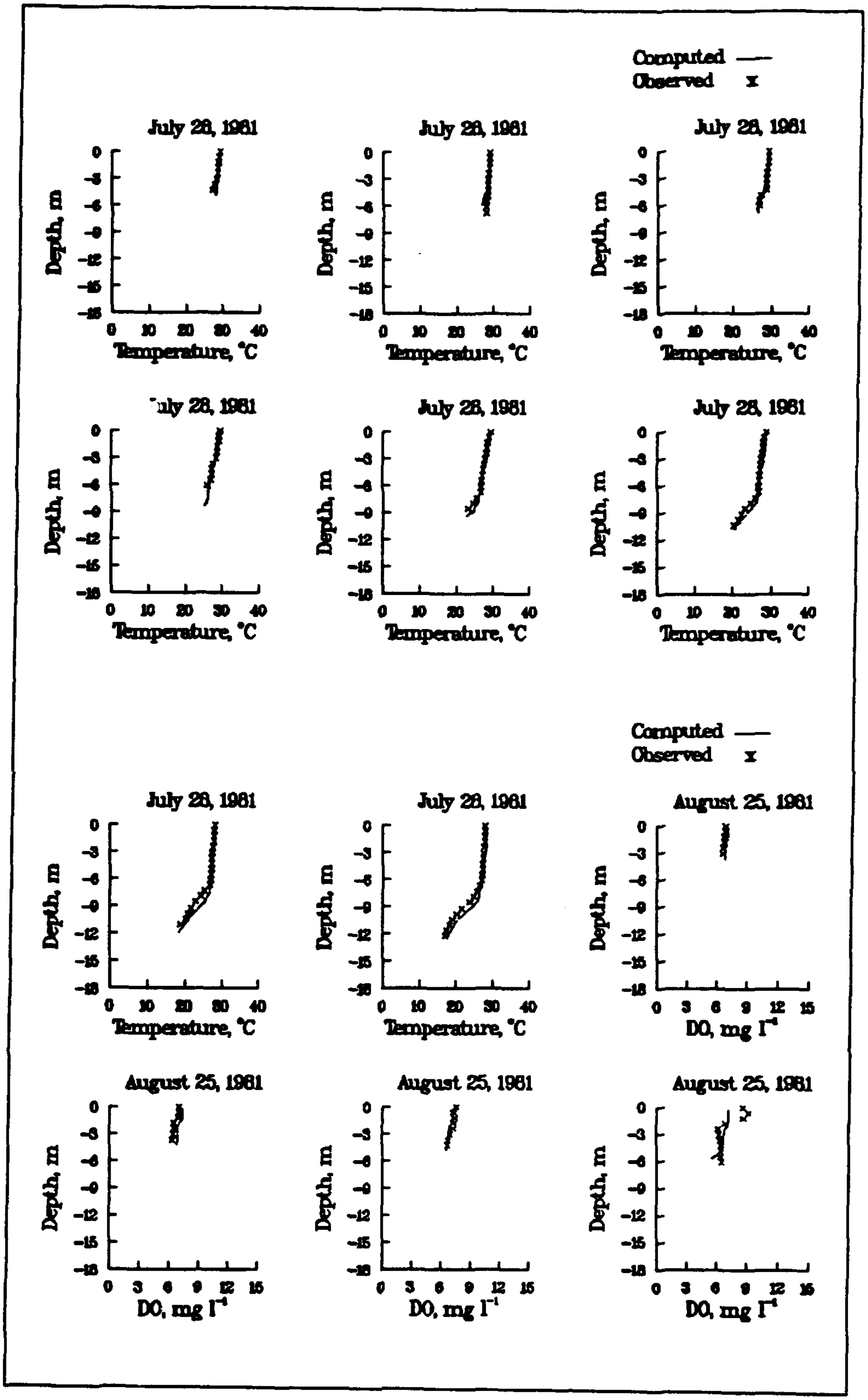


Figure B4. (Sheet 2 of 5)

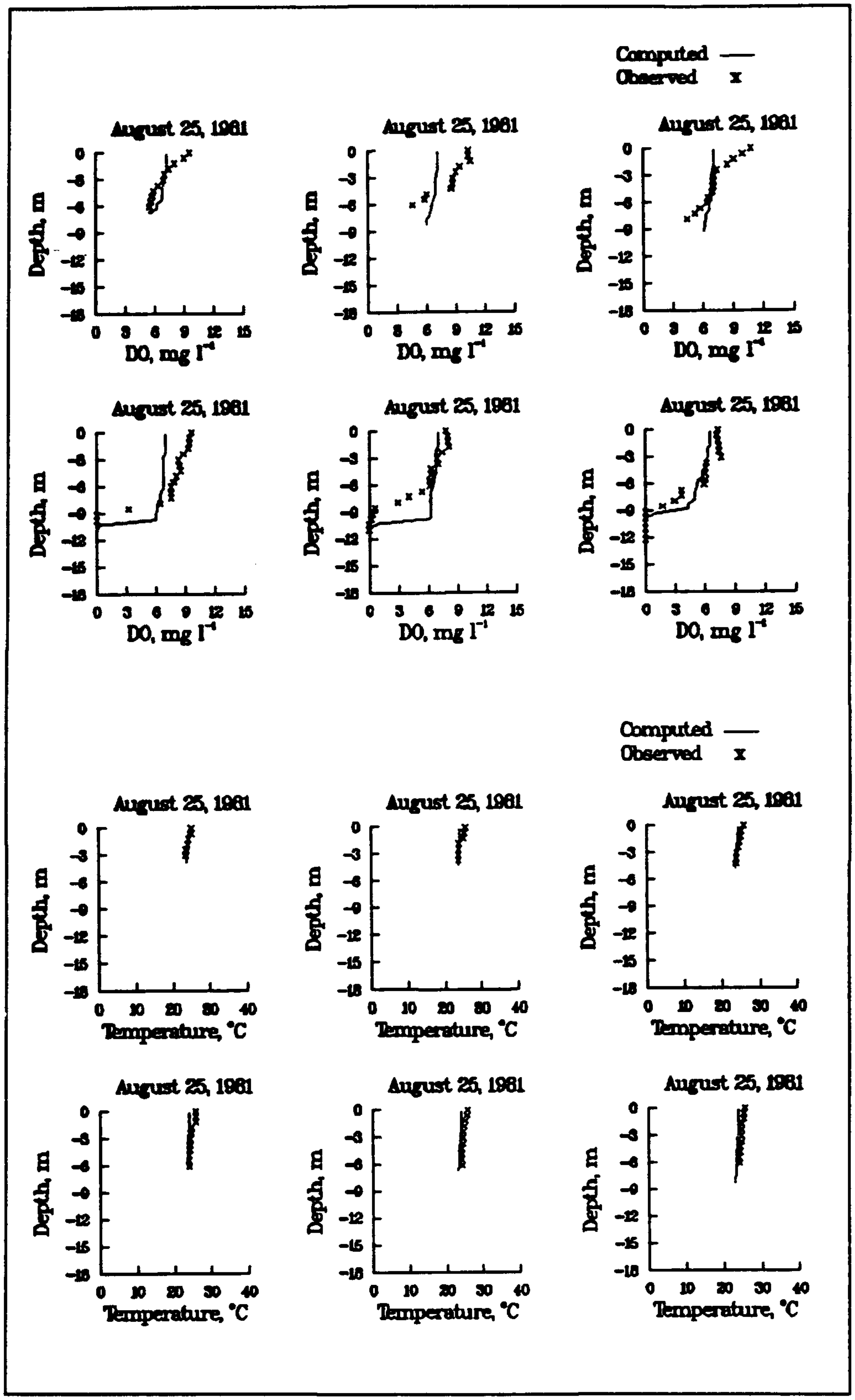


Figure B4. (Sheet 3 of 5)

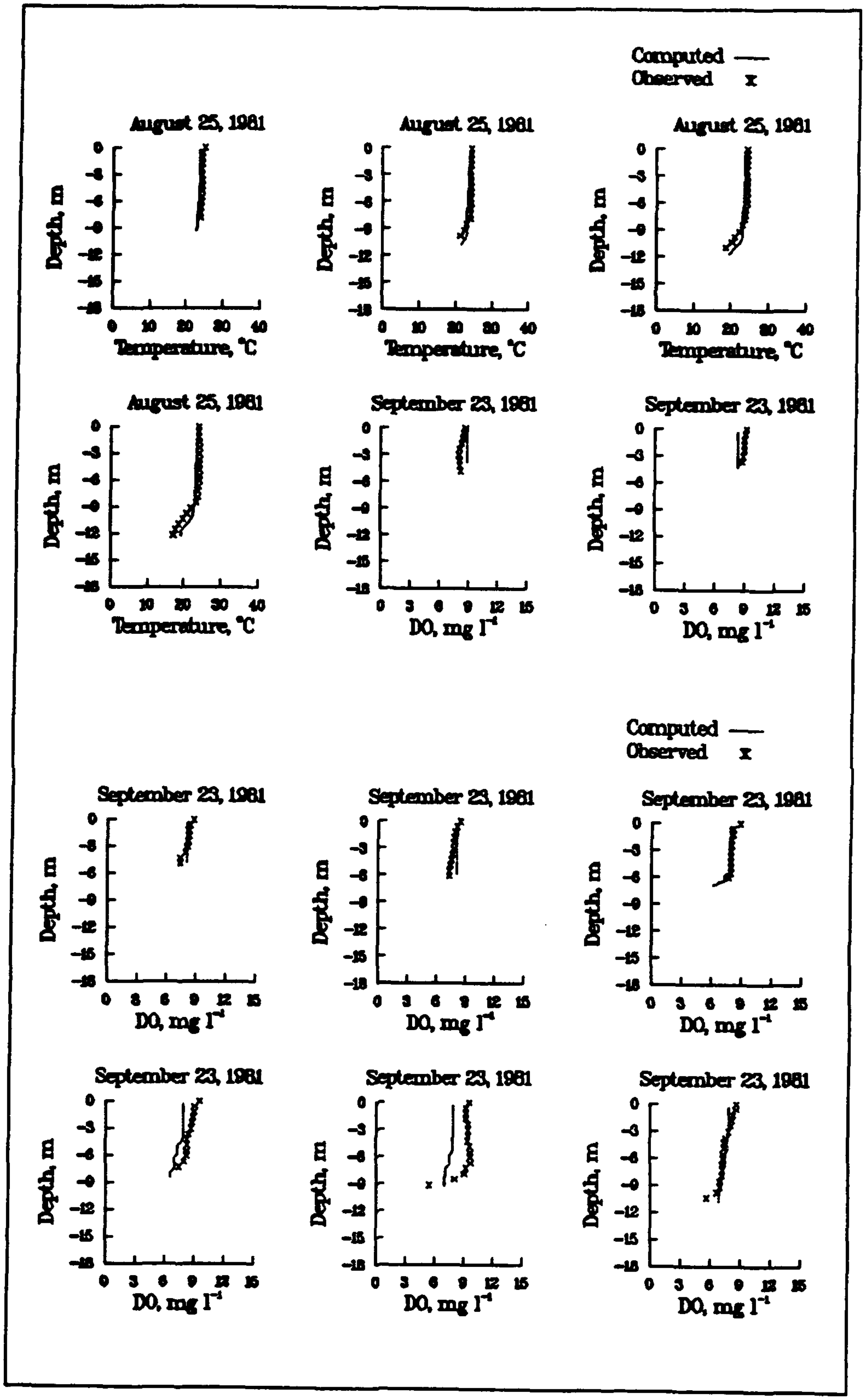


Figure B4. (Sheet 4 of 5)

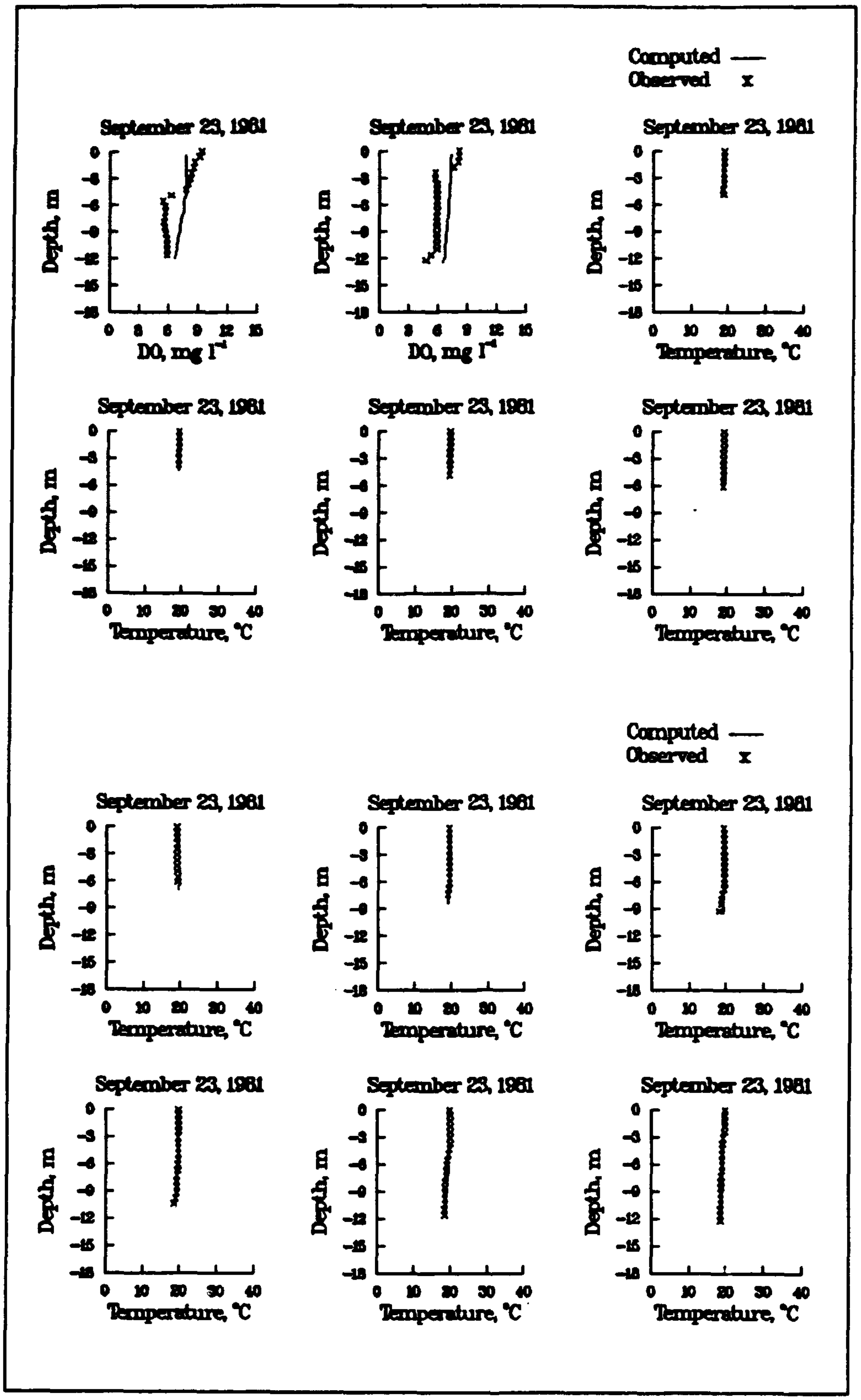


Figure B4. (Sheet 5 of 5)

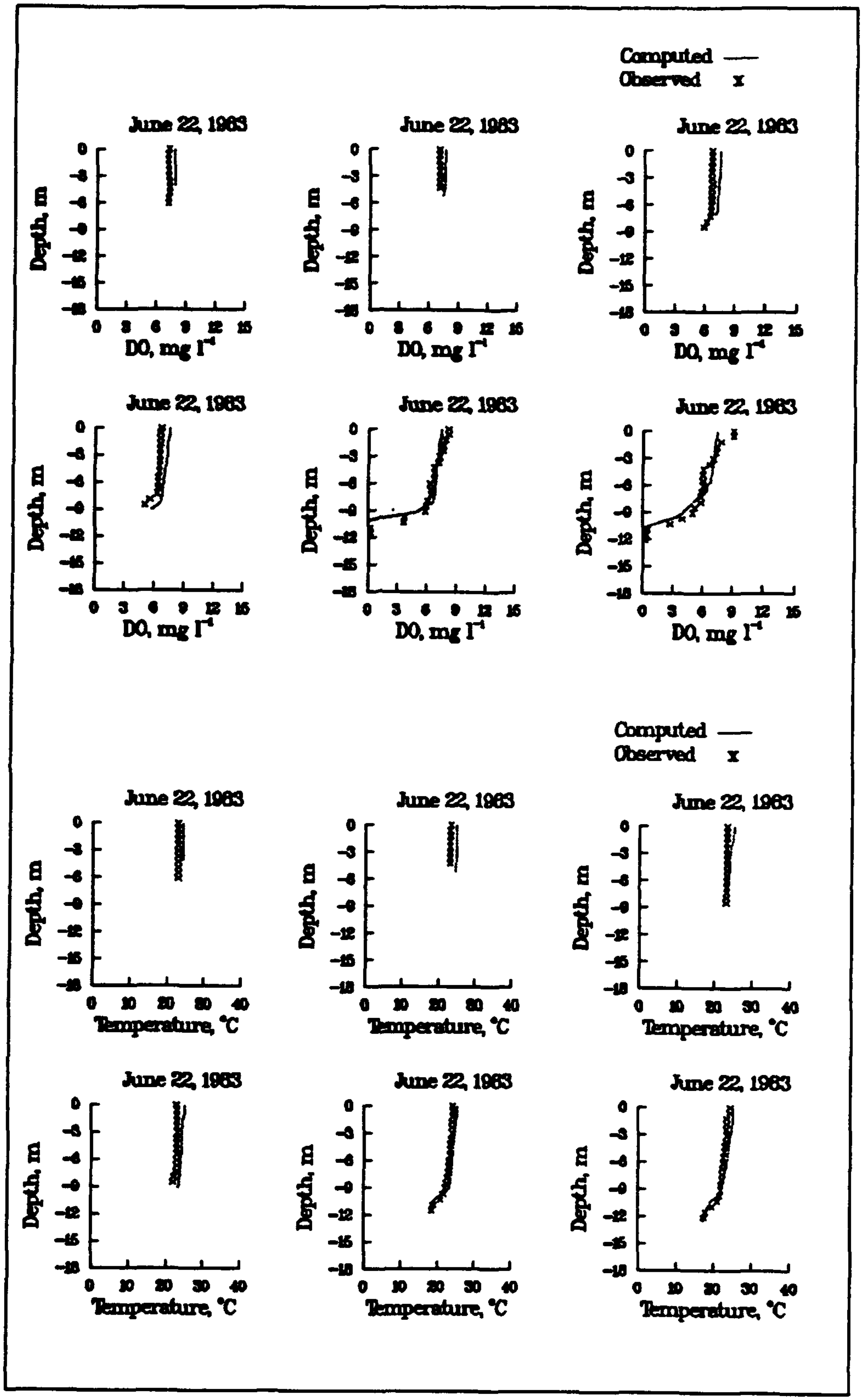


Figure B5. Sensitivity analysis results from increasing SOD parameter 50 percent for 1983 (Sheet 1 of 5)

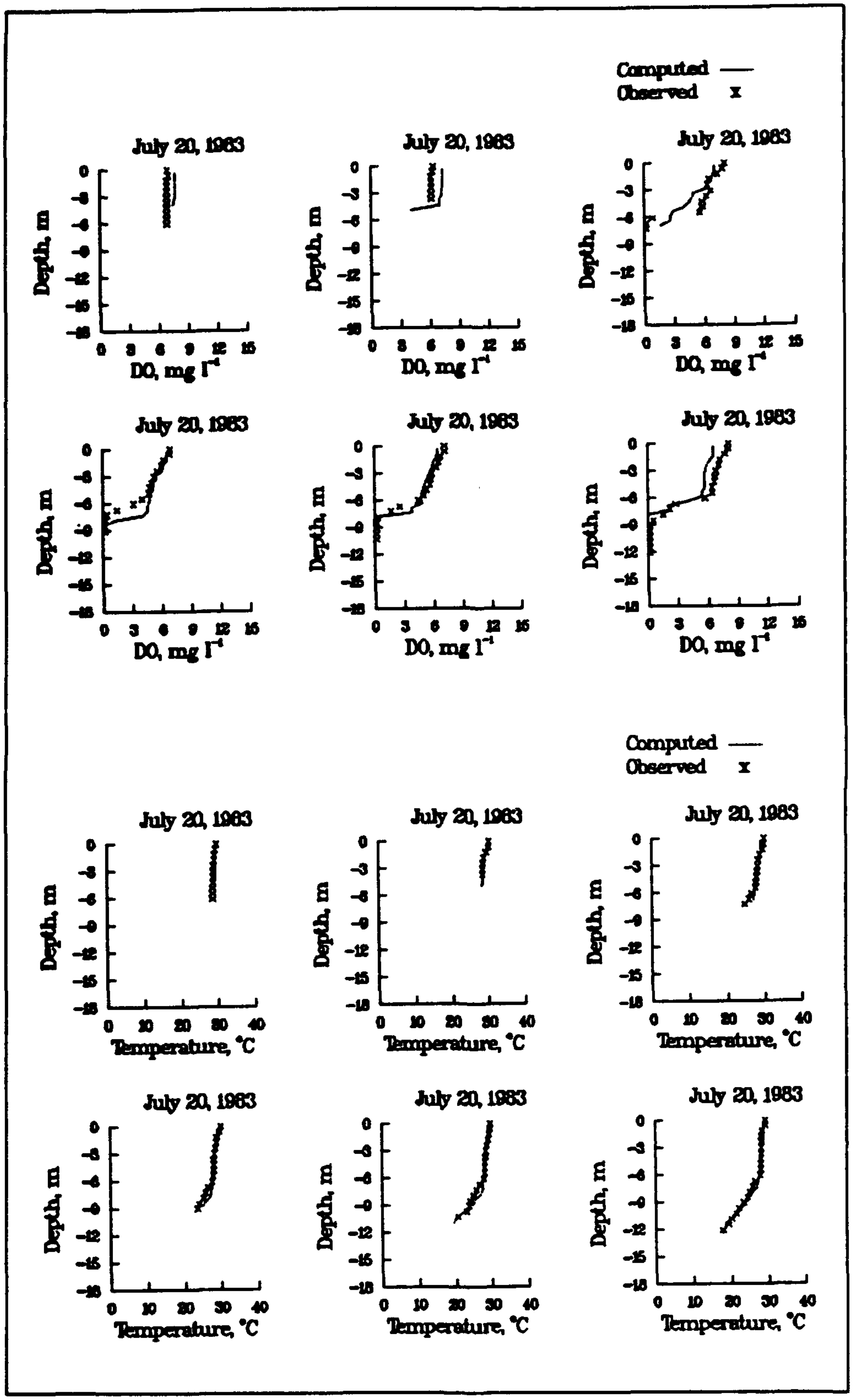


Figure B5. (Sheet 2 of 5)

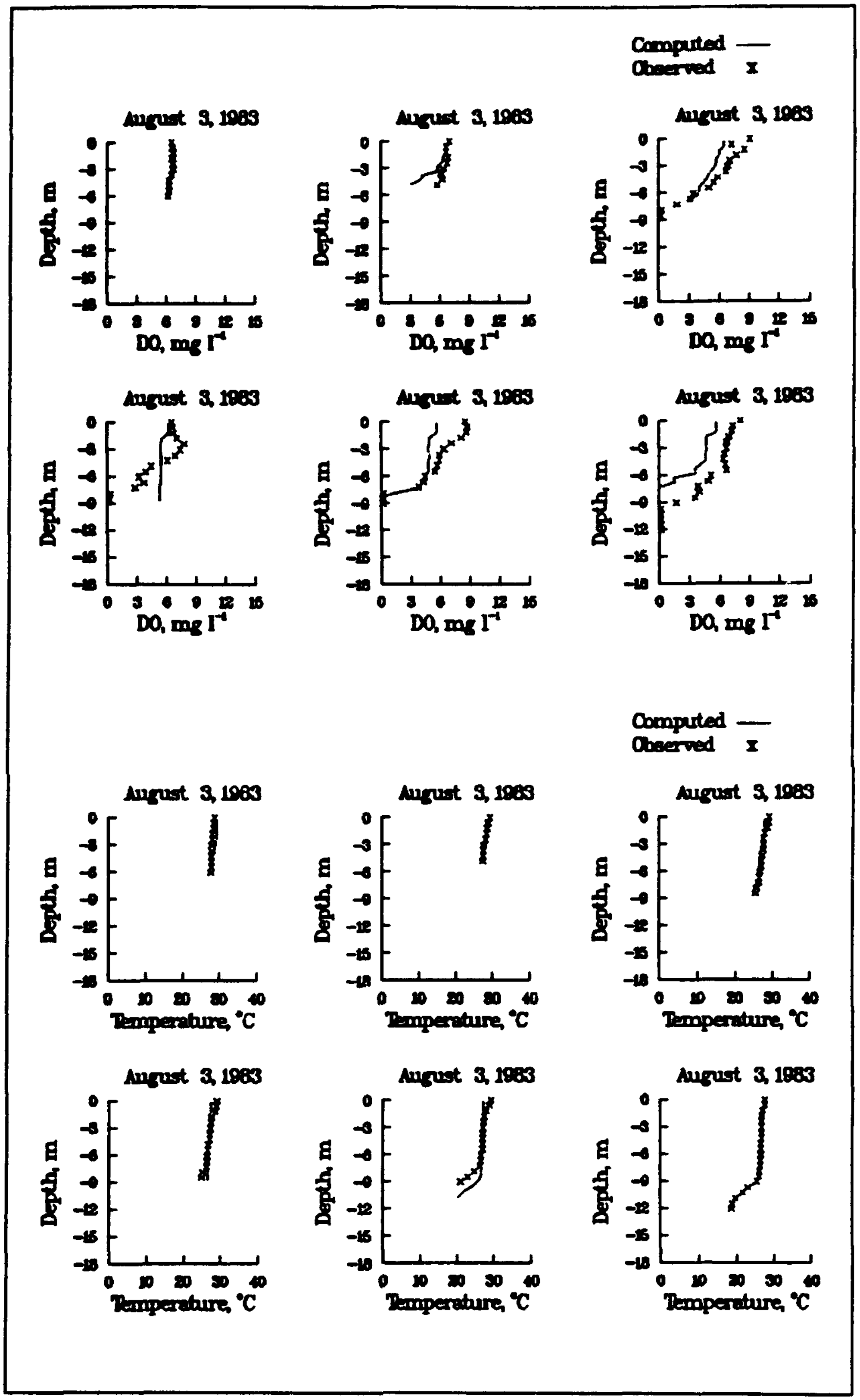


Figure B5. (Sheet 3 of 5)

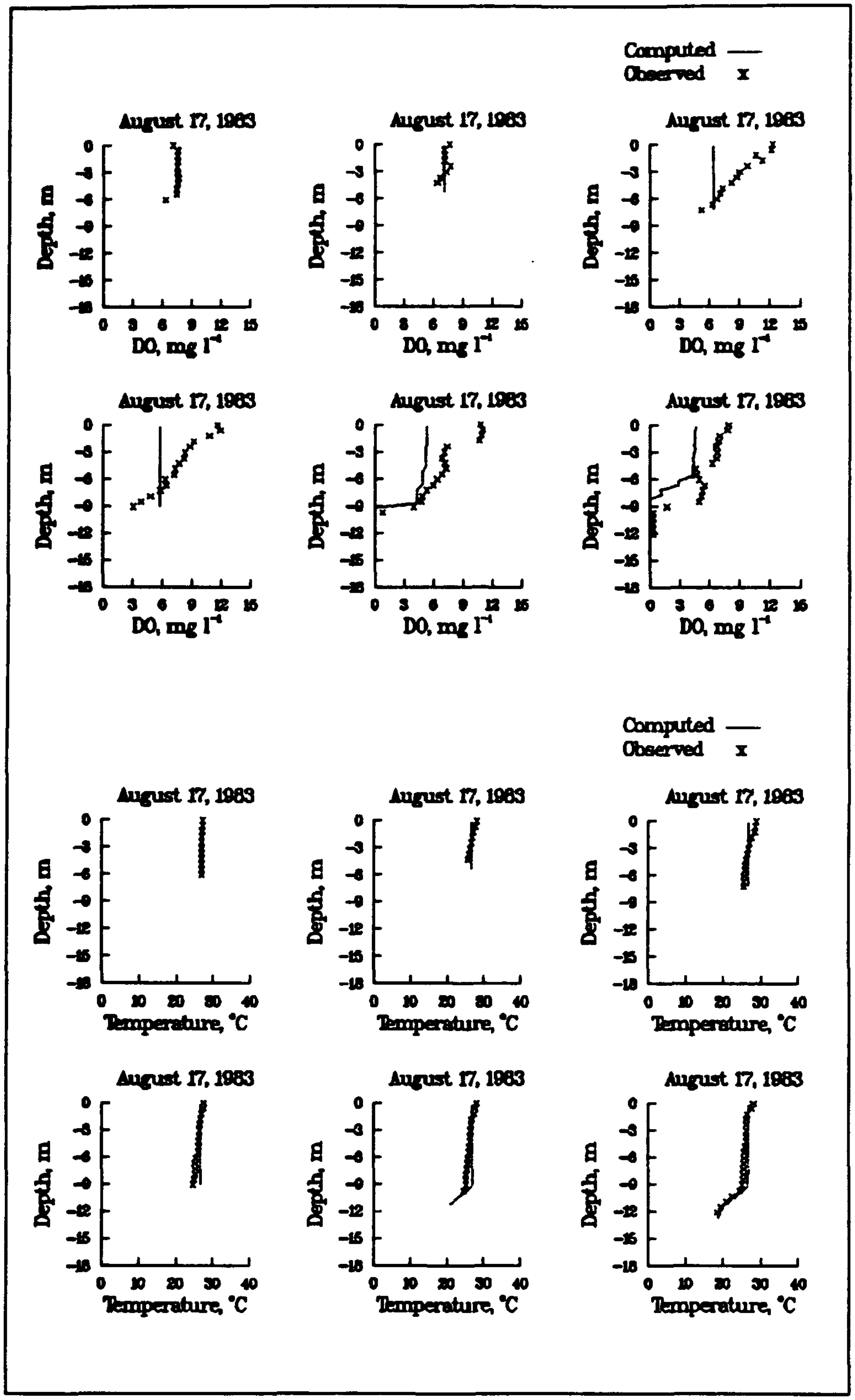


Figure B5. (Sheet 4 of 5)

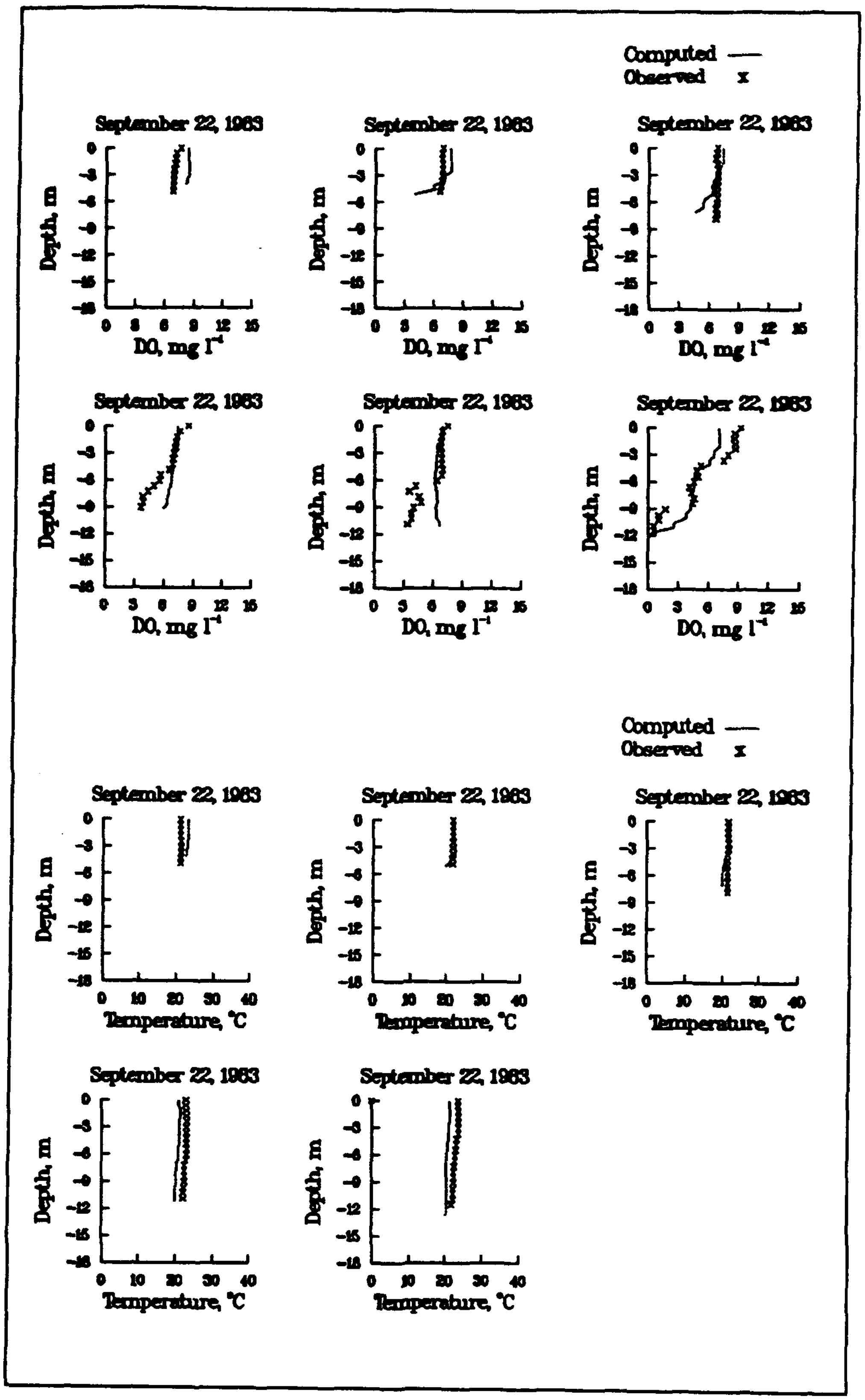


Figure B5. (Sheet 5 of 5)

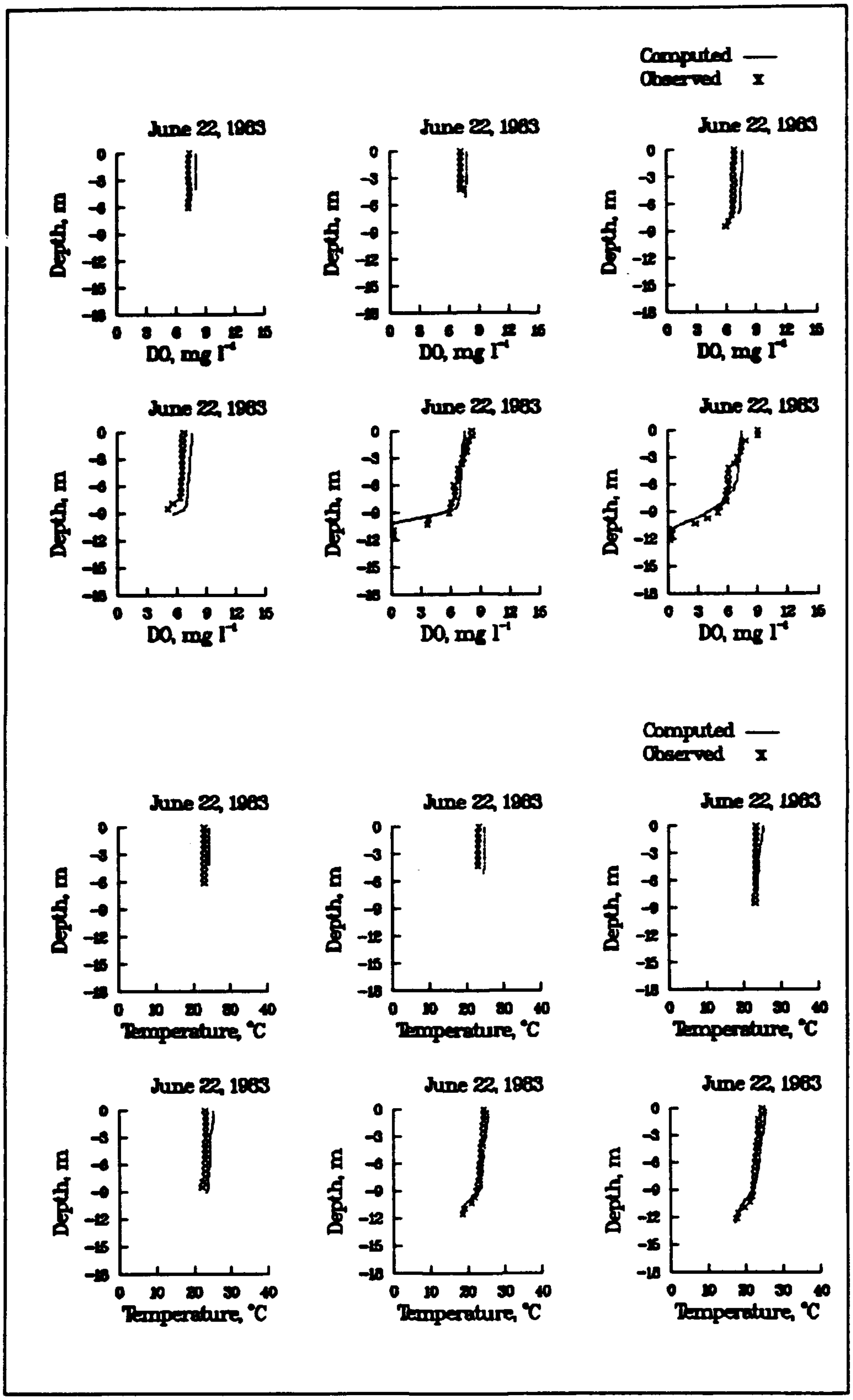


Figure B6. Sensitivity analysis results from decreasing SOD parameter 50 percent for 1983 (Sheet 1 of 5)

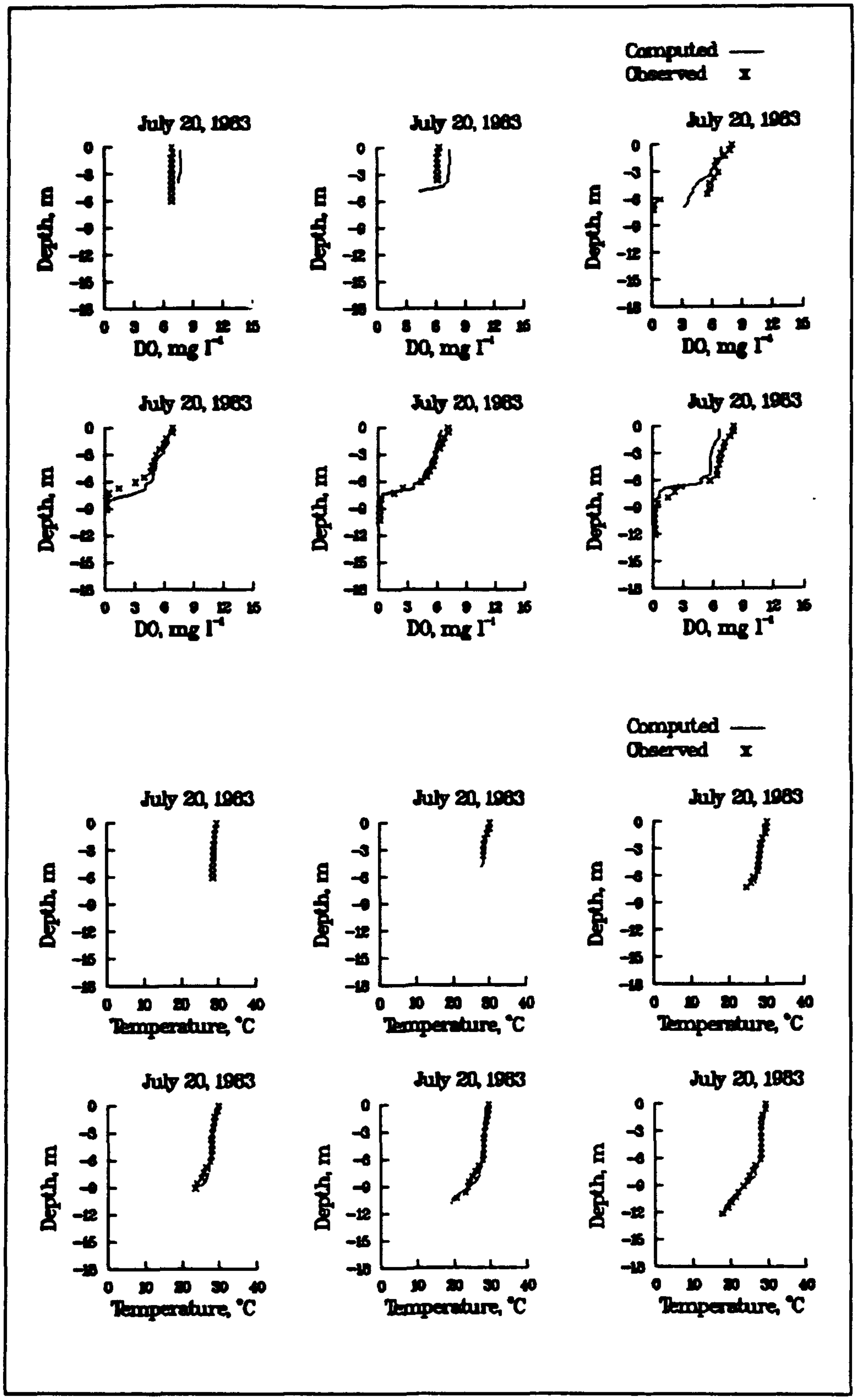


Figure B6. (Sheet 2 of 5)

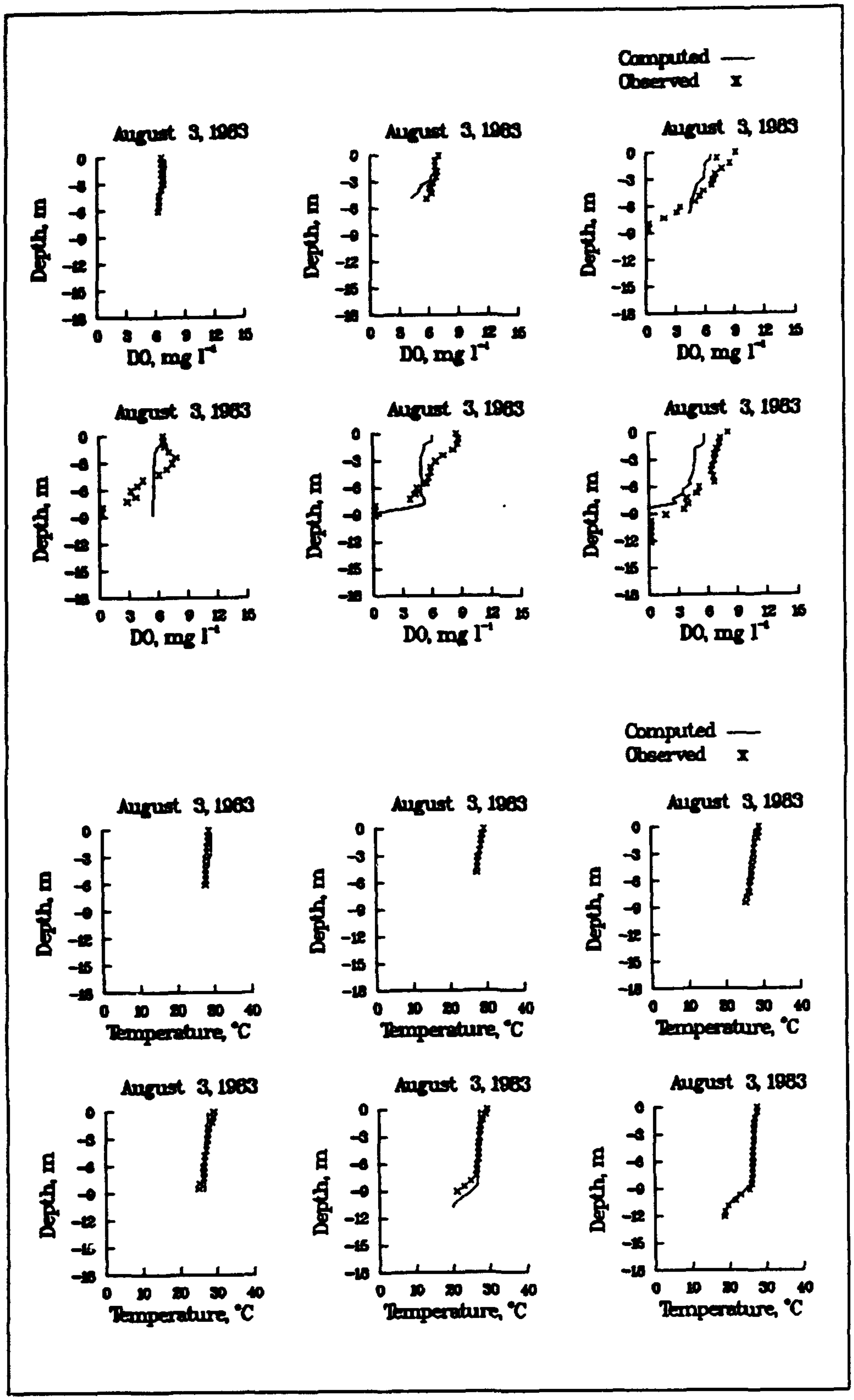


Figure B6. (Sheet 3 of 5)

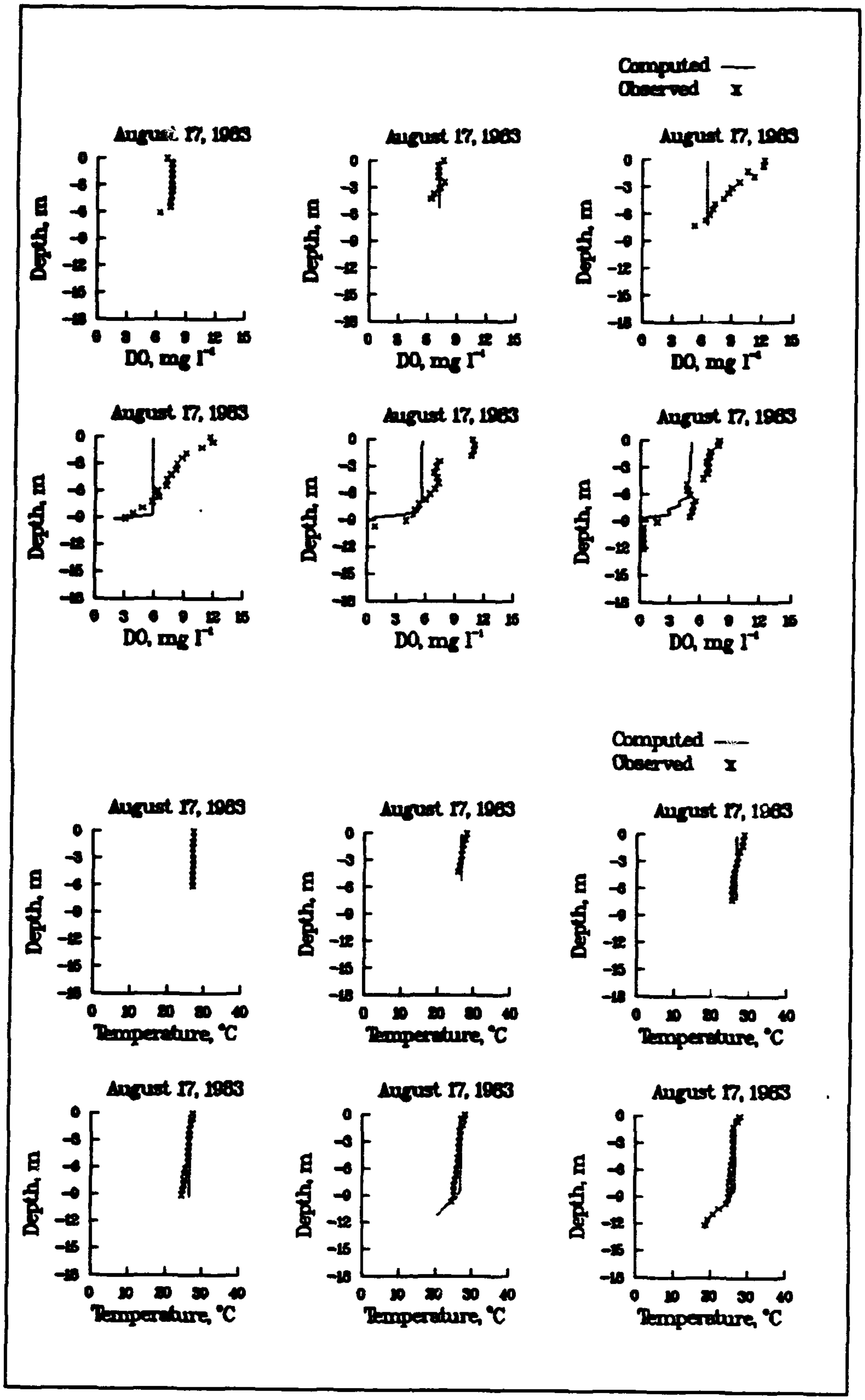


Figure B6. (Sheet 4 of 5)

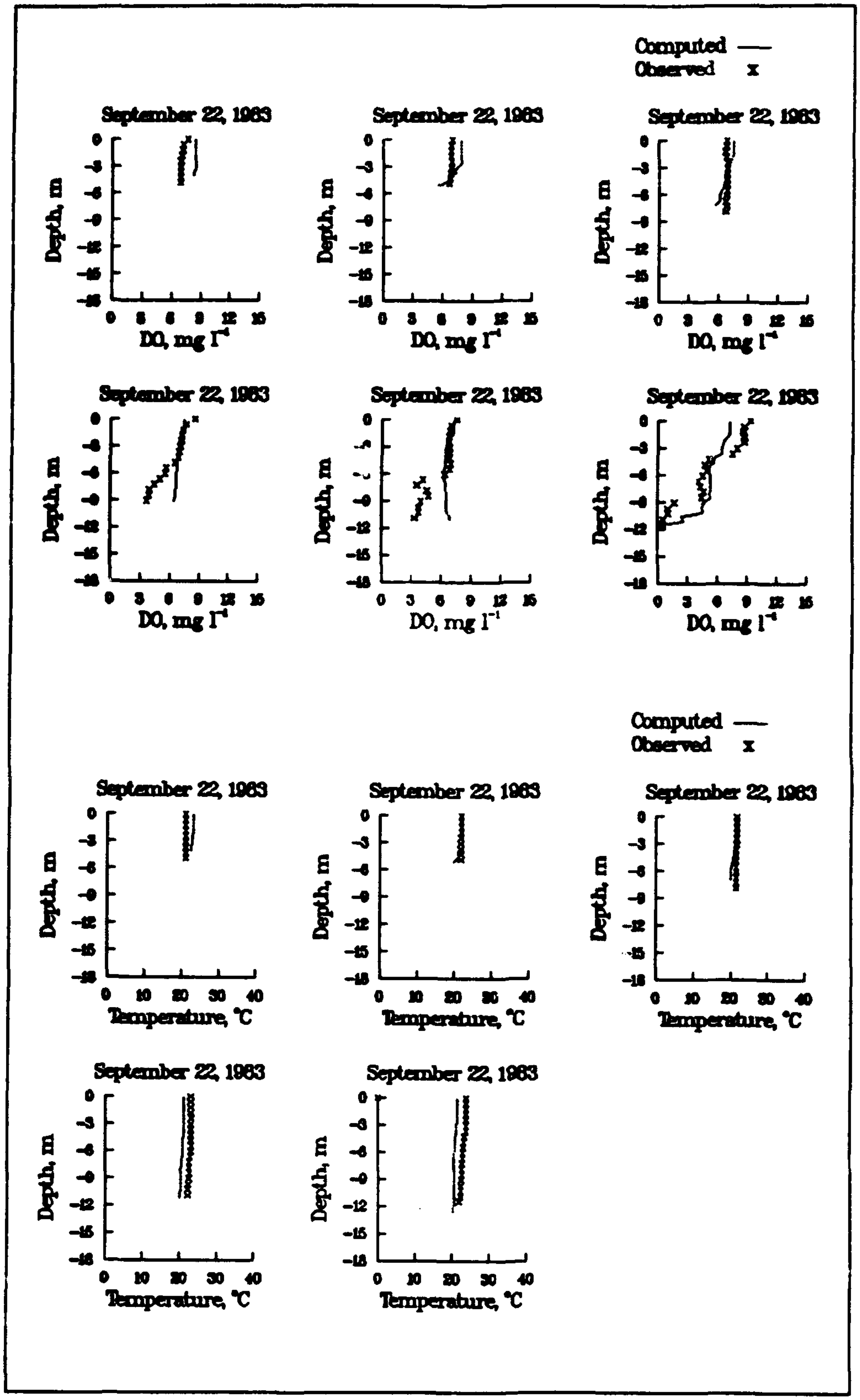


Figure B6. (Sheet 5 of 5)

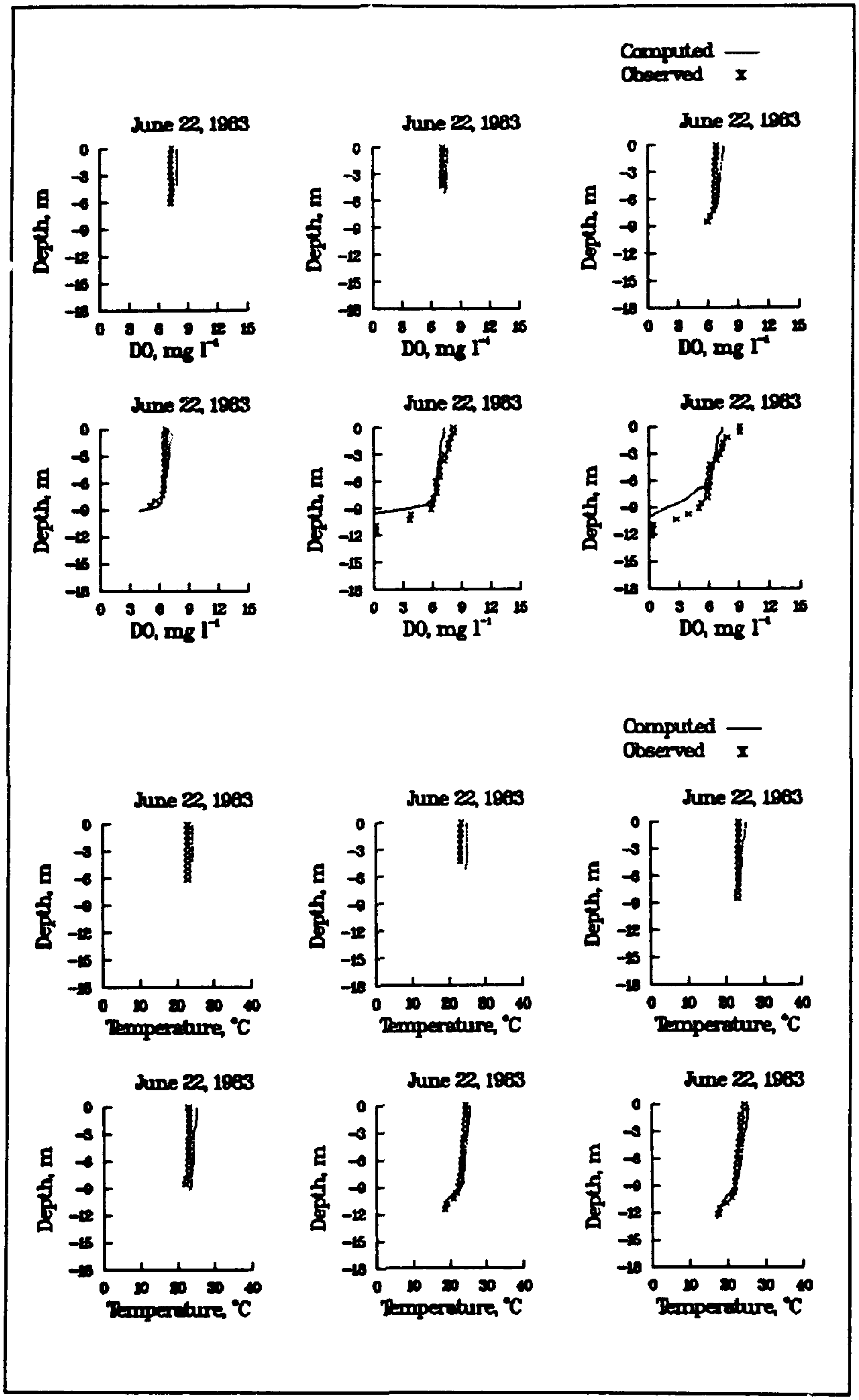


Figure B7. Sensitivity analysis results from increasing WCOD parameter 50 percent for 1983 (Sheet 1 of 5)

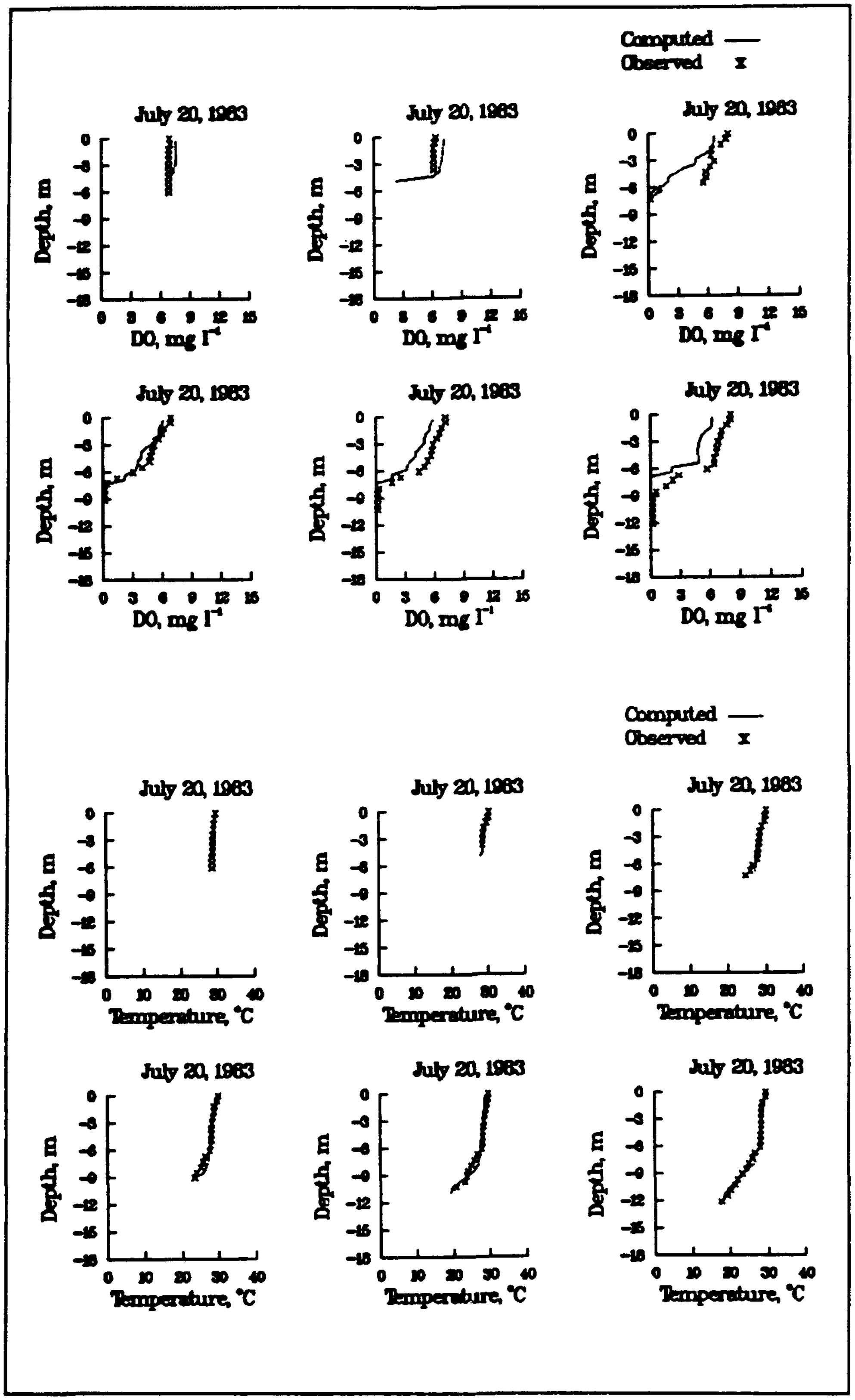


Figure B7. (Sheet 2 of 5)

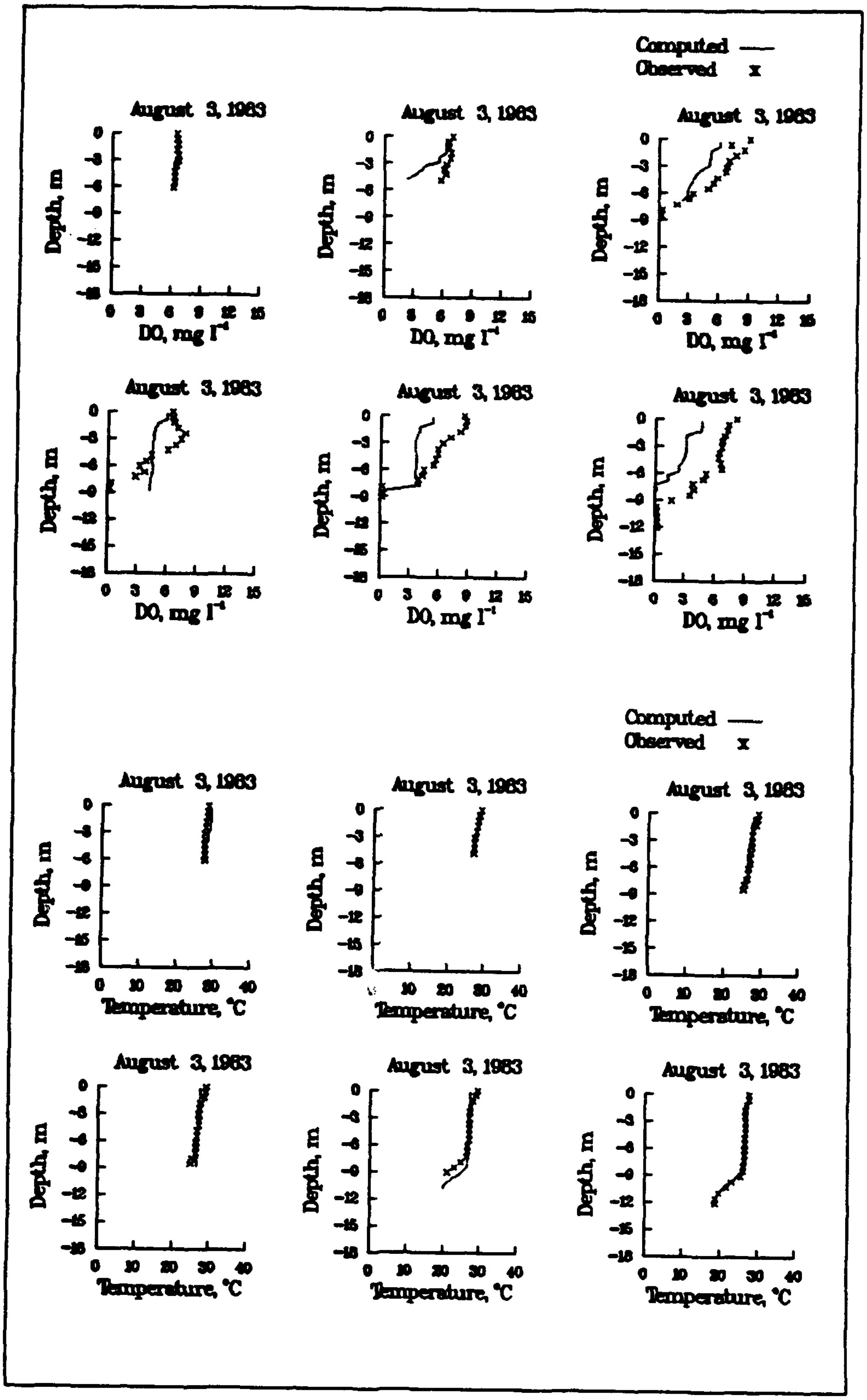


Figure B7. (Sheet 3 of 5)

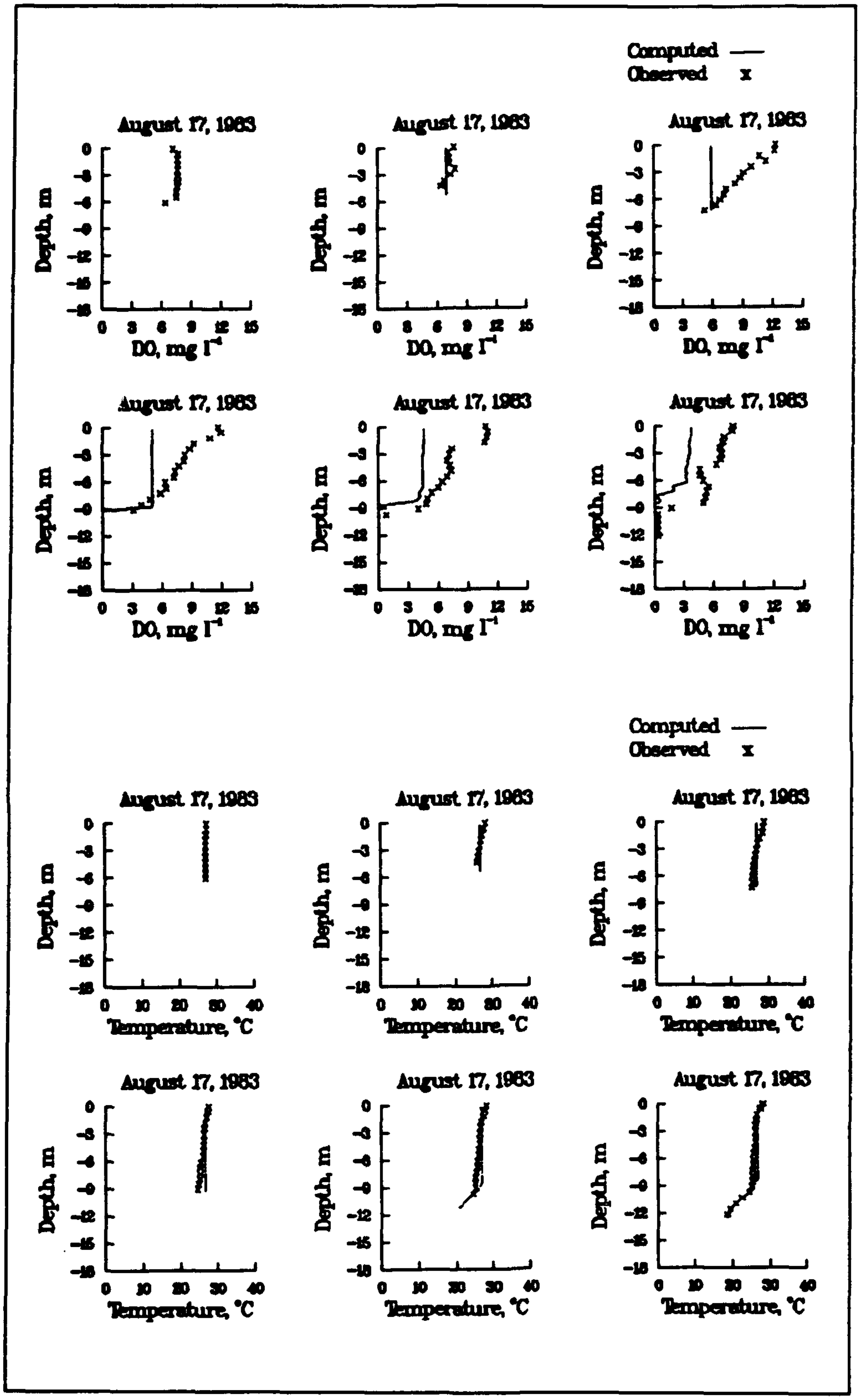


Figure B7. (Sheet 4 of 5)

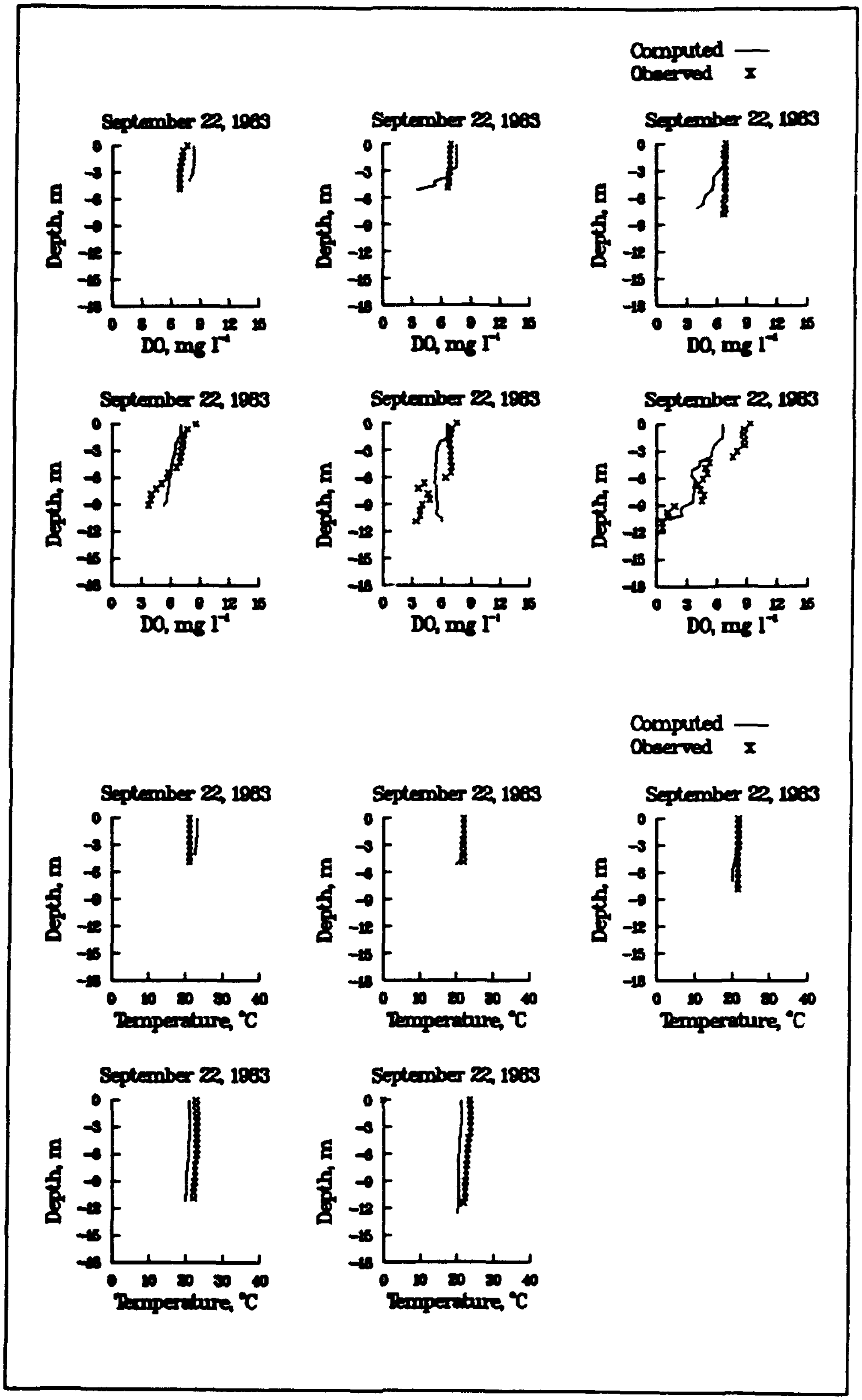


Figure B7. (Sheet 5 of 5)

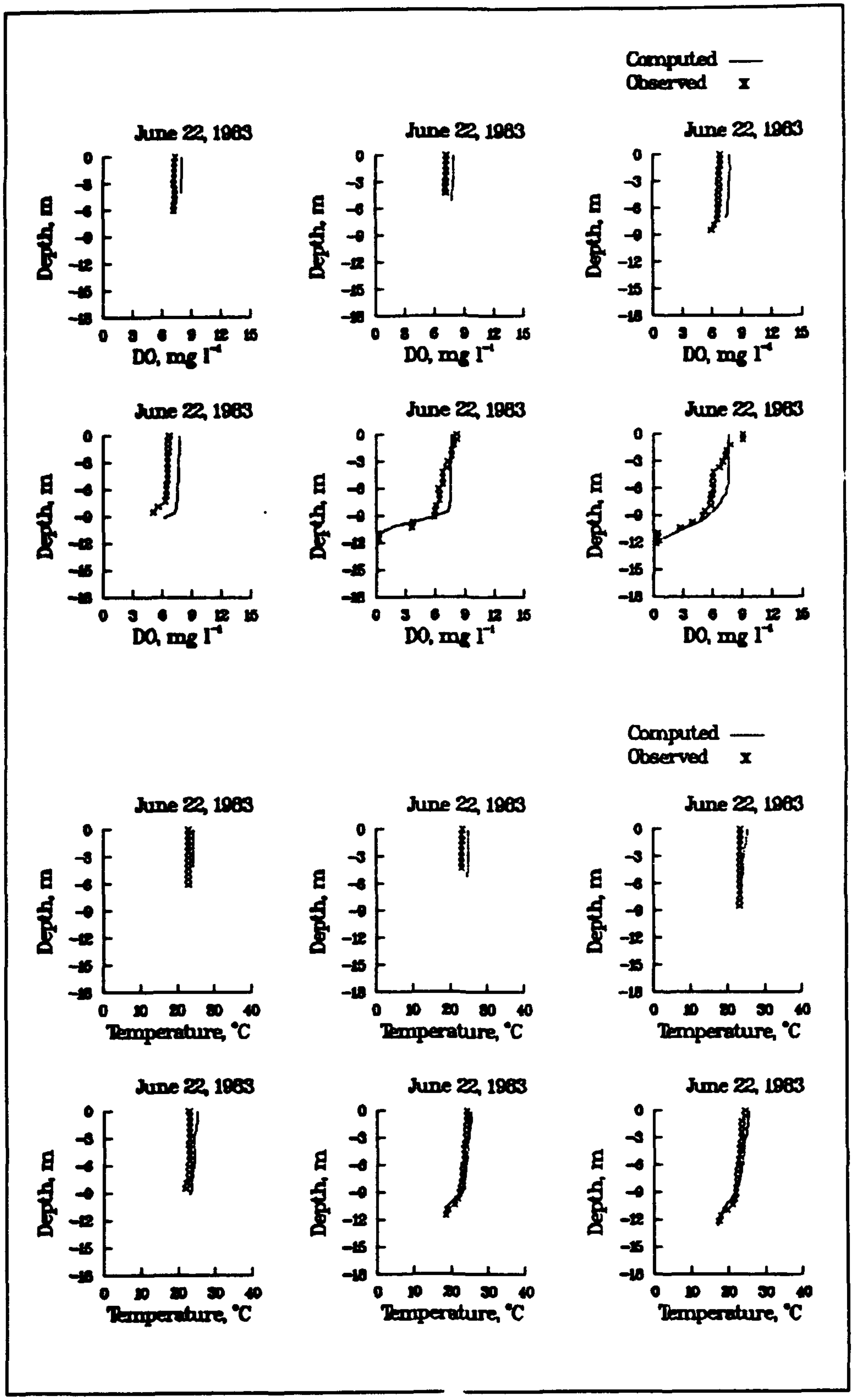


Figure B8. Sensitivity analysis results from decreasing WCOD parameter 50 percent for 1983 (Sheet 1 of 5)

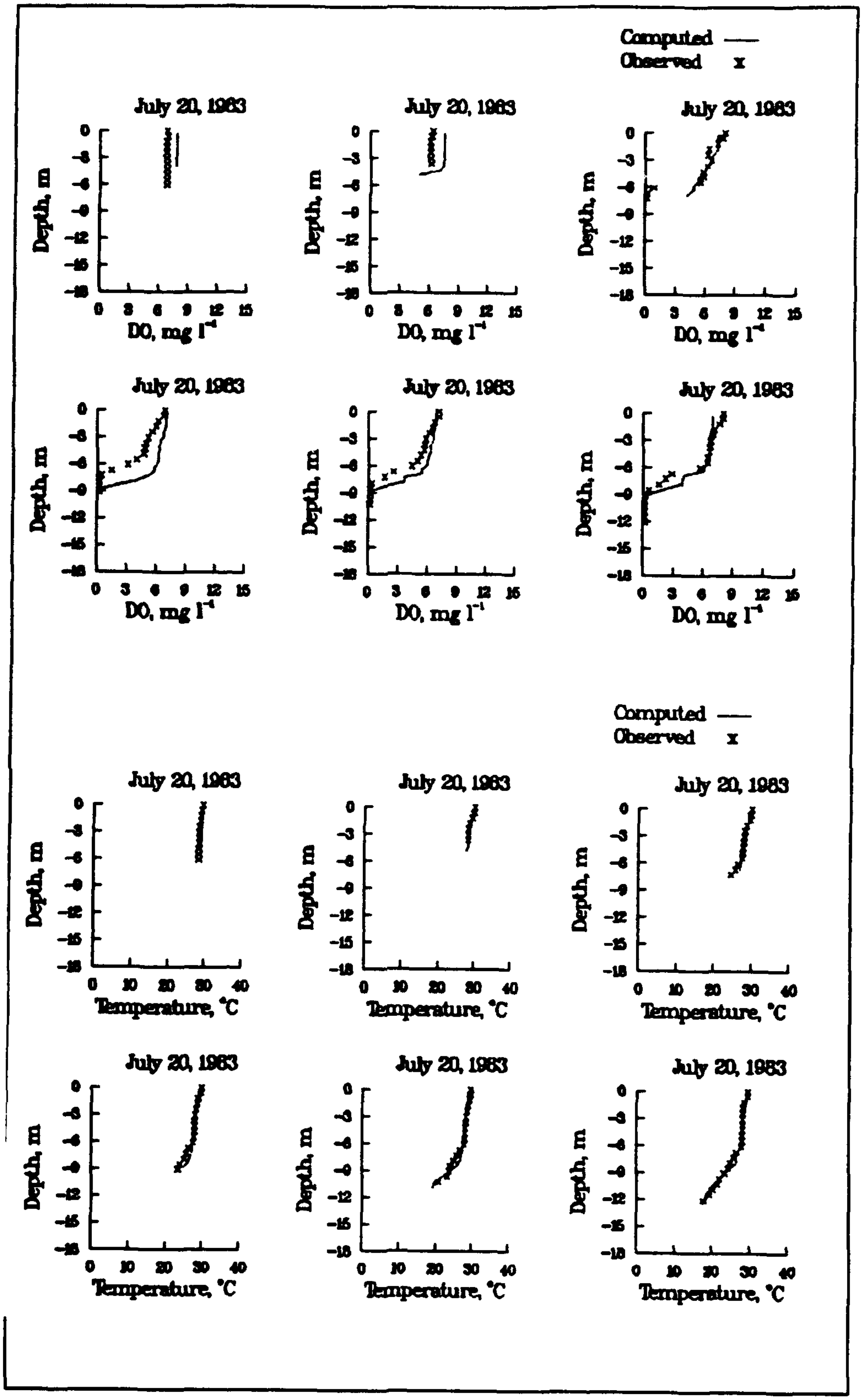


Figure B8. (Sheet 2 of 5)

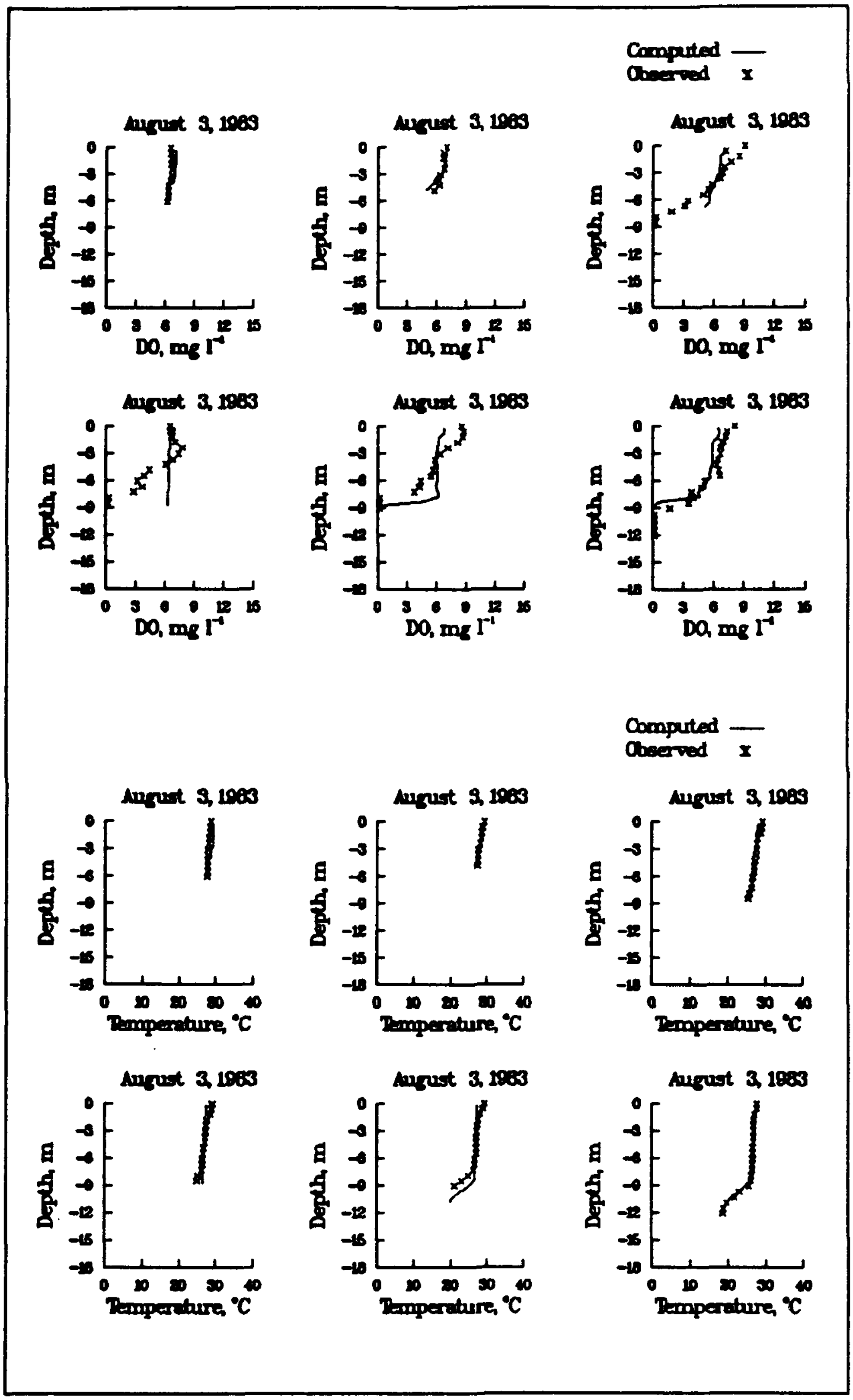


Figure B8. (Sheet 3 of 5)

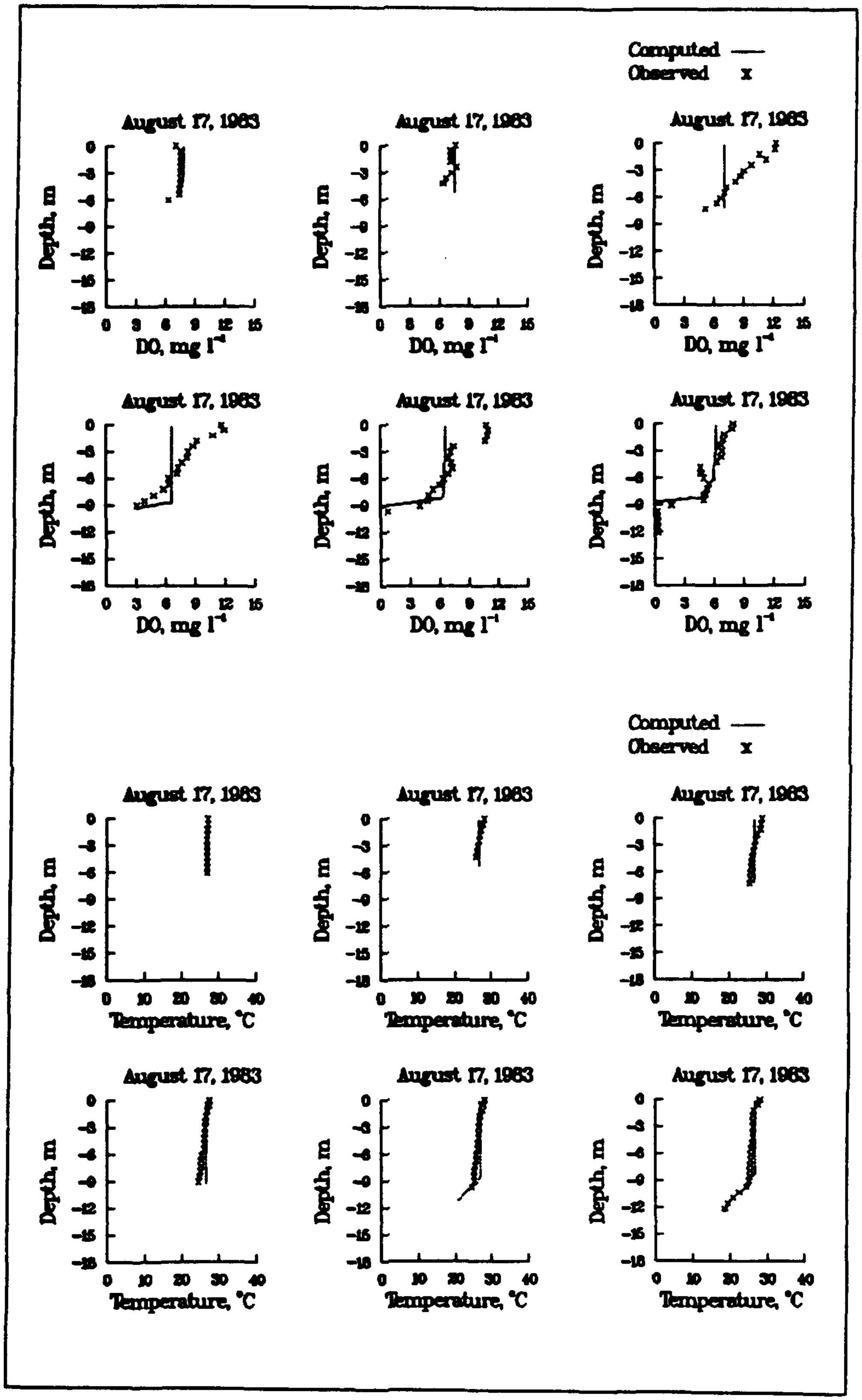


Figure B8. (Sheet 4 of 5)

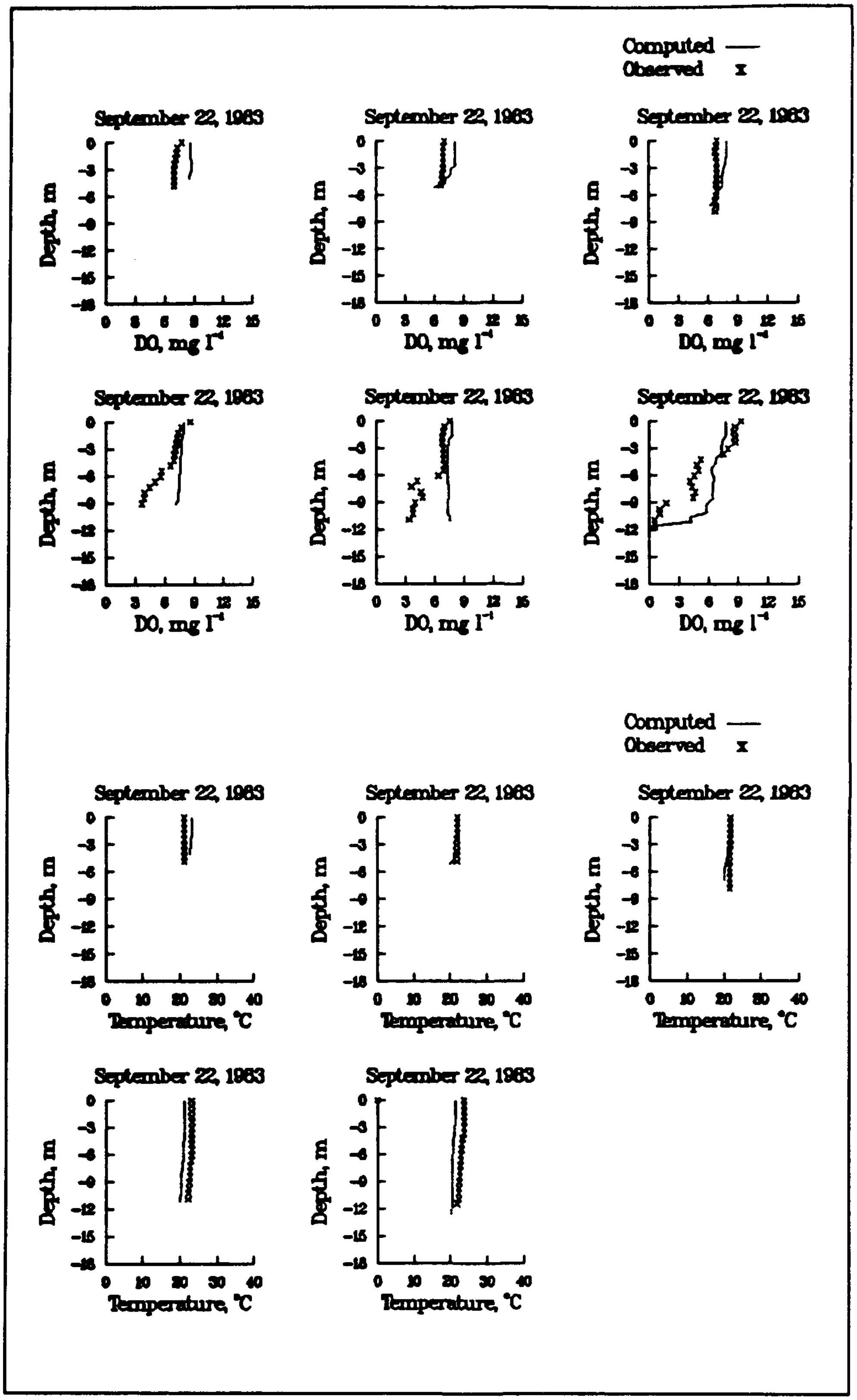


Figure B8. (Sheet 5 of 5)

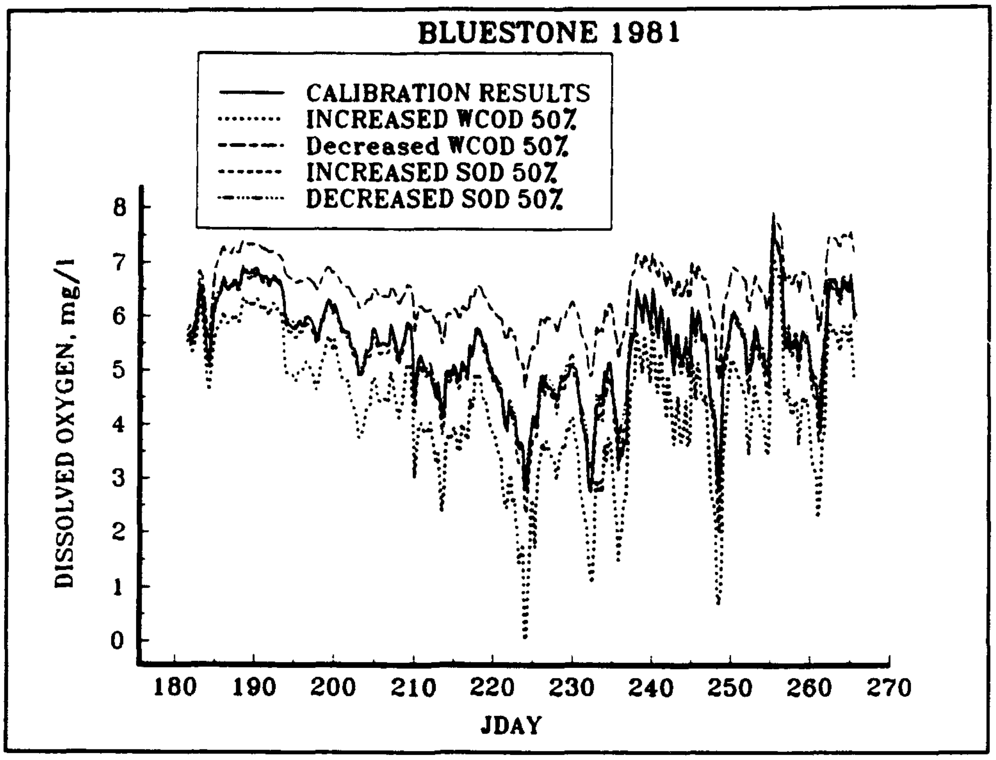


Figure B9. Comparison plot of sensitivity analysis results and calibration results

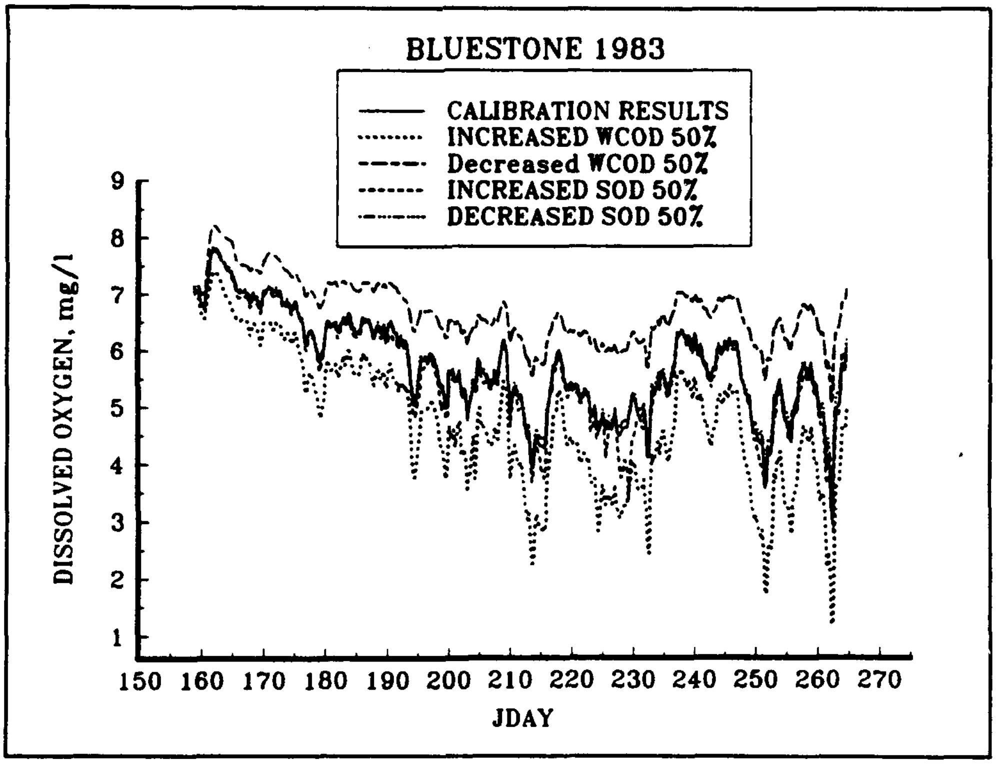


Figure B10. Comparison plot of sensitivity analysis results and verification results

Appendix C
Scenario Results

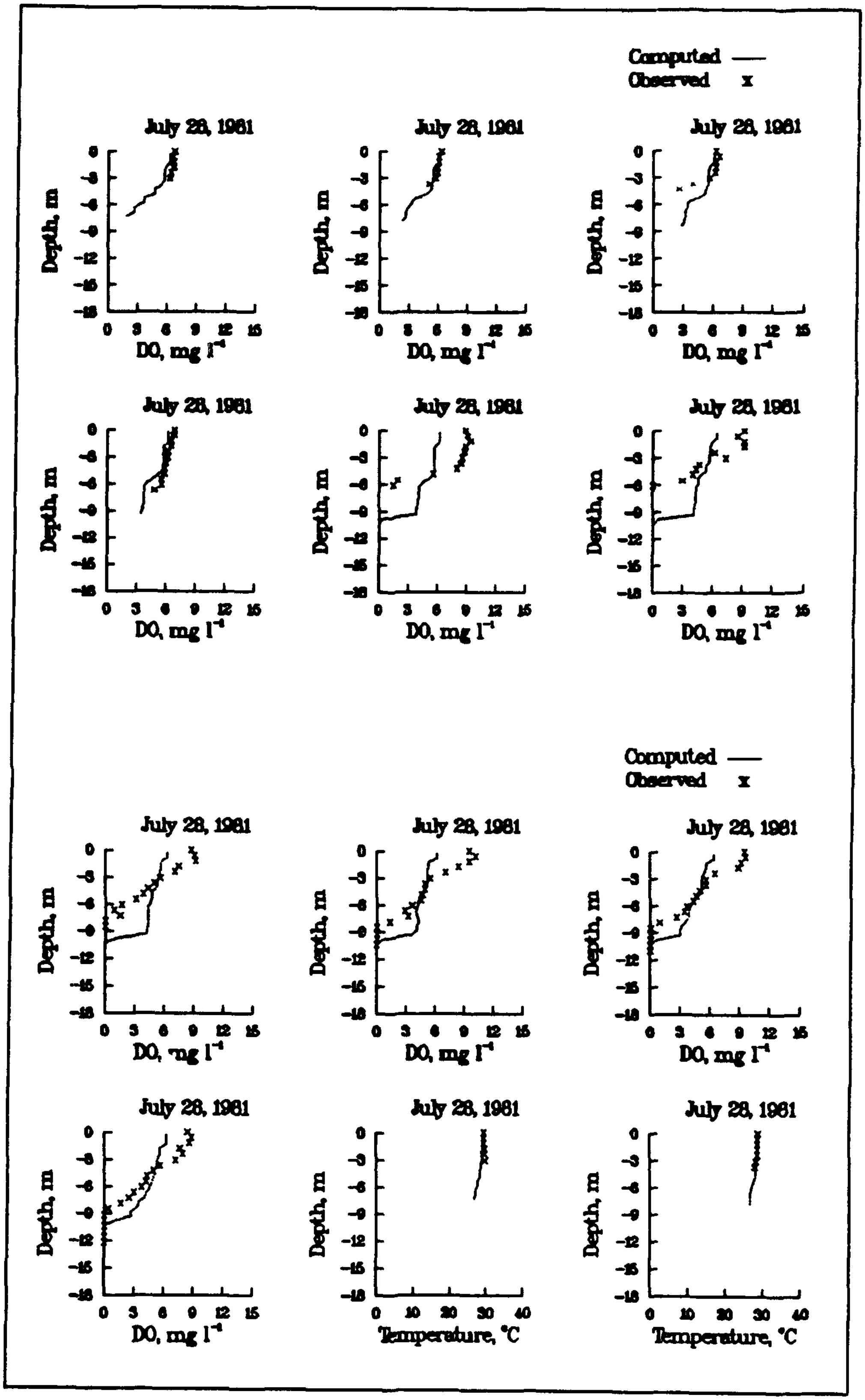


Figure C1. Scenario 1 results from increasing pool 11 ft for 1981 and 1983 (Sheet 1 of 10)

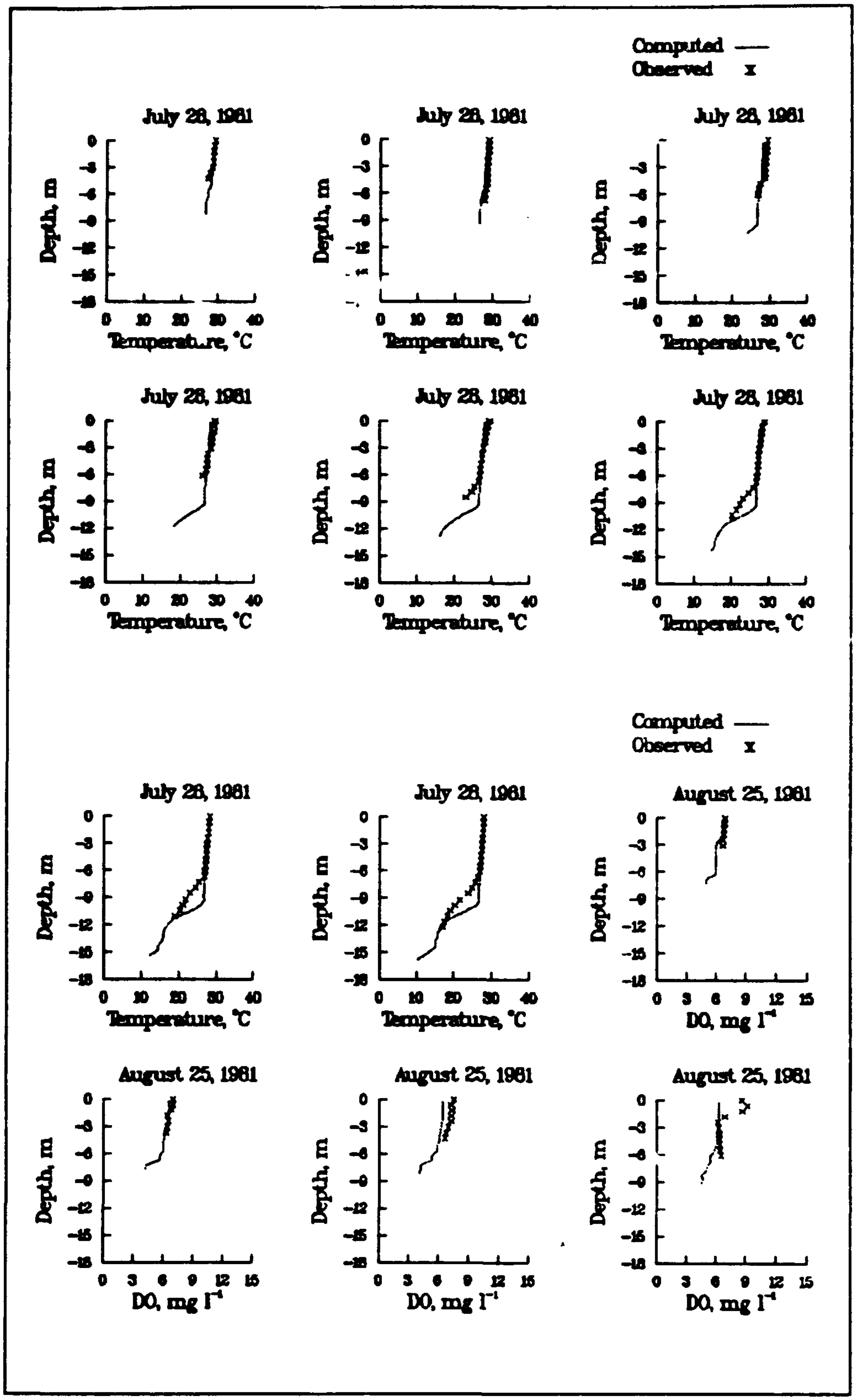
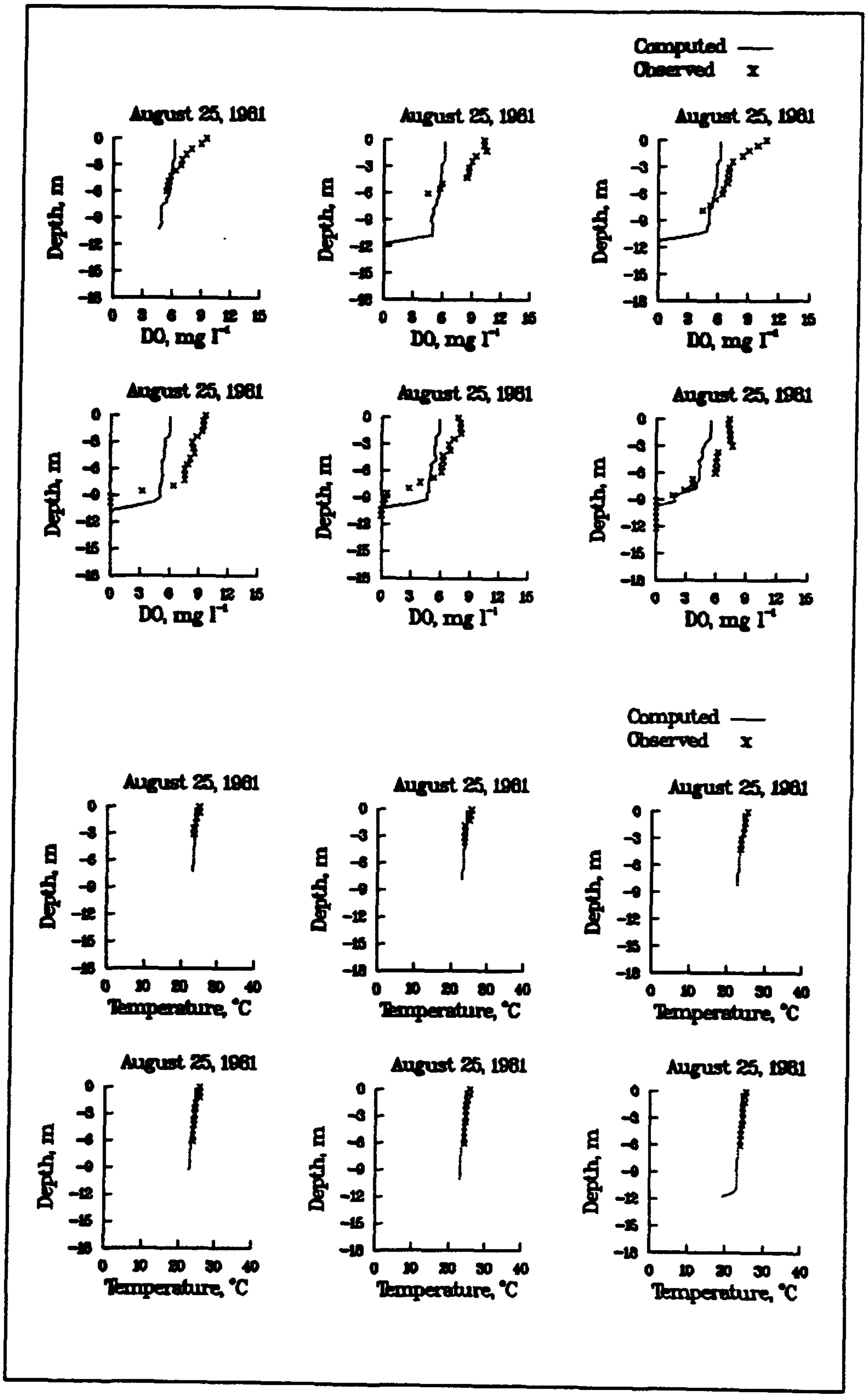


Figure C1. (Sheet 2 of 10)



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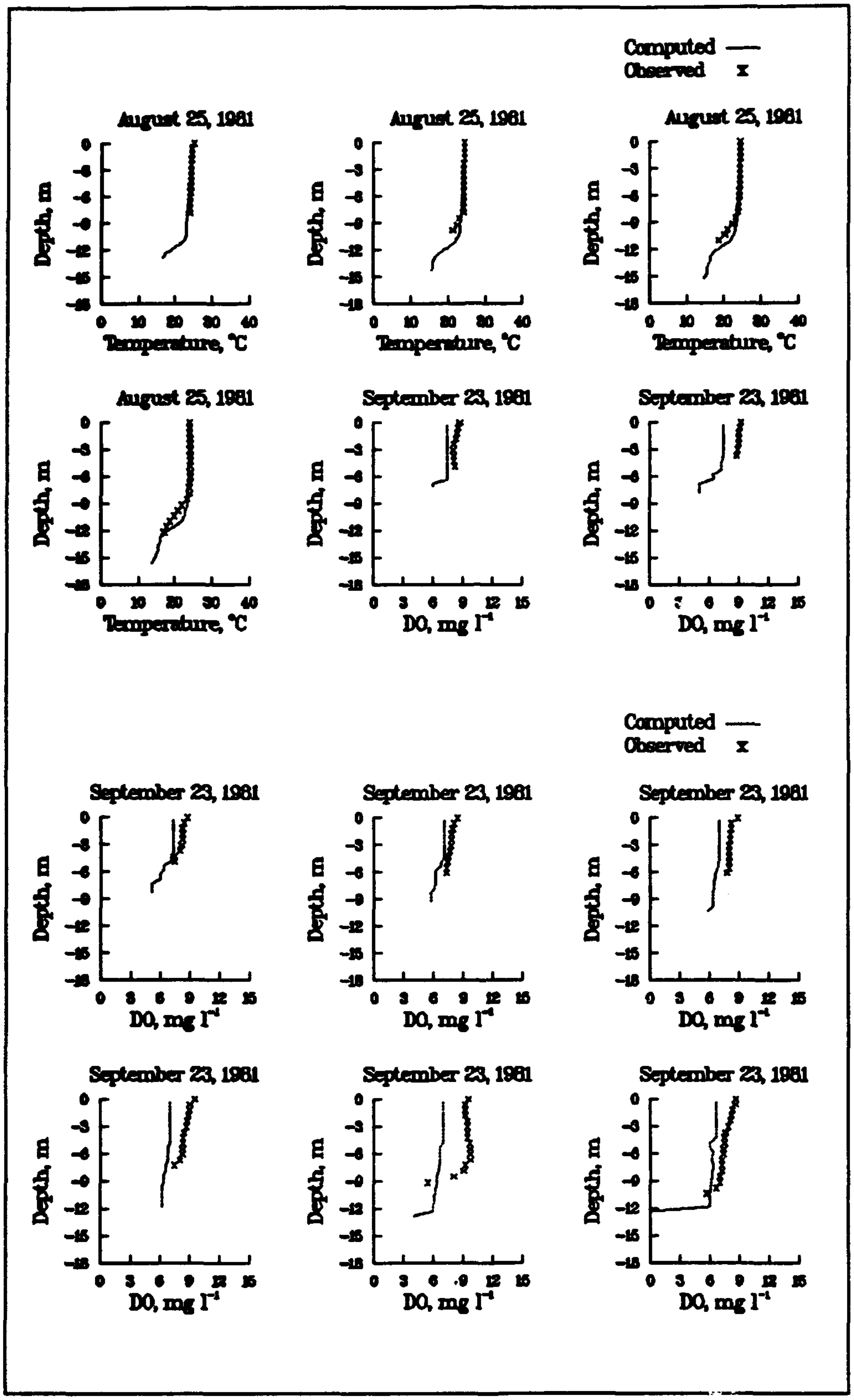

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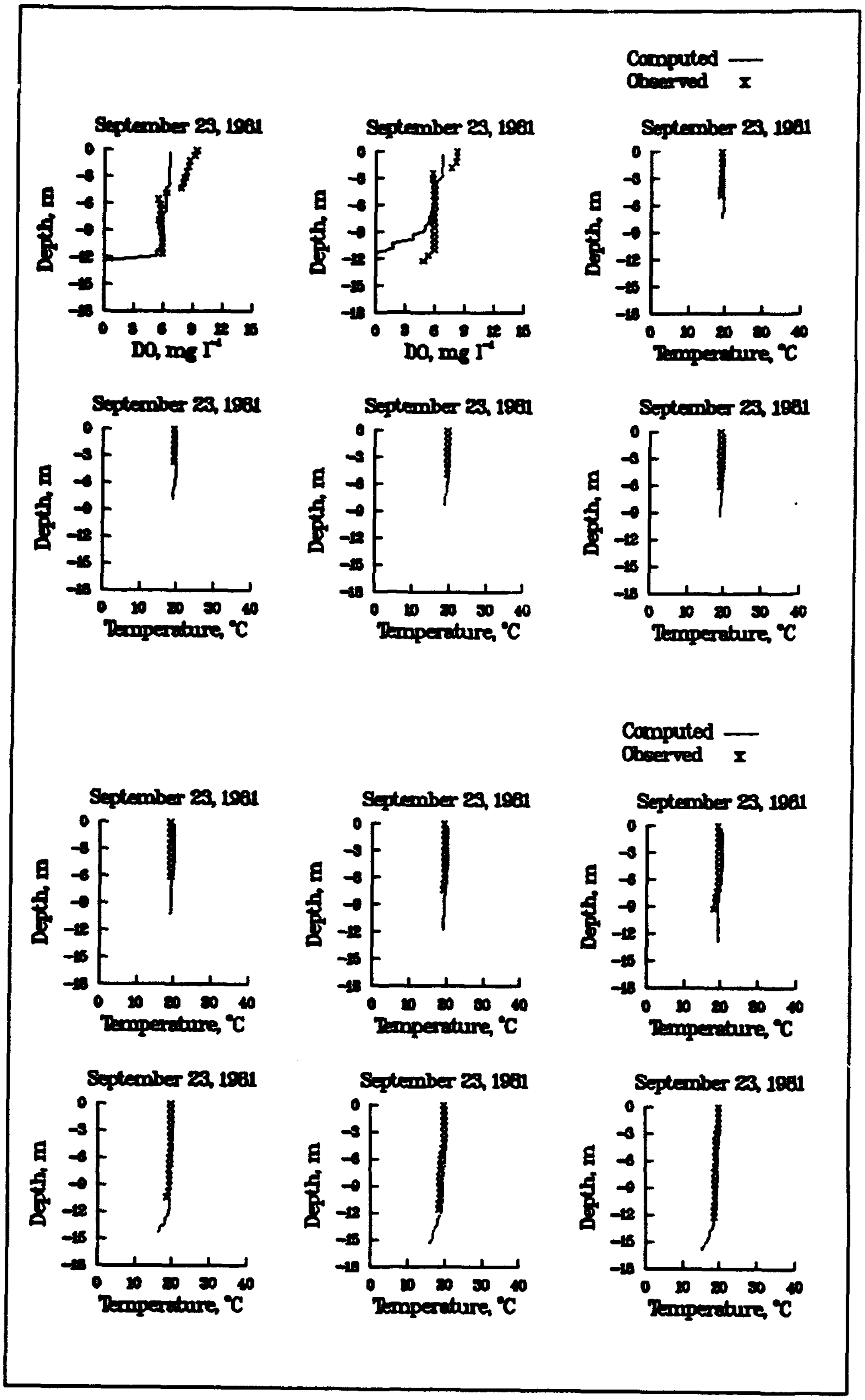

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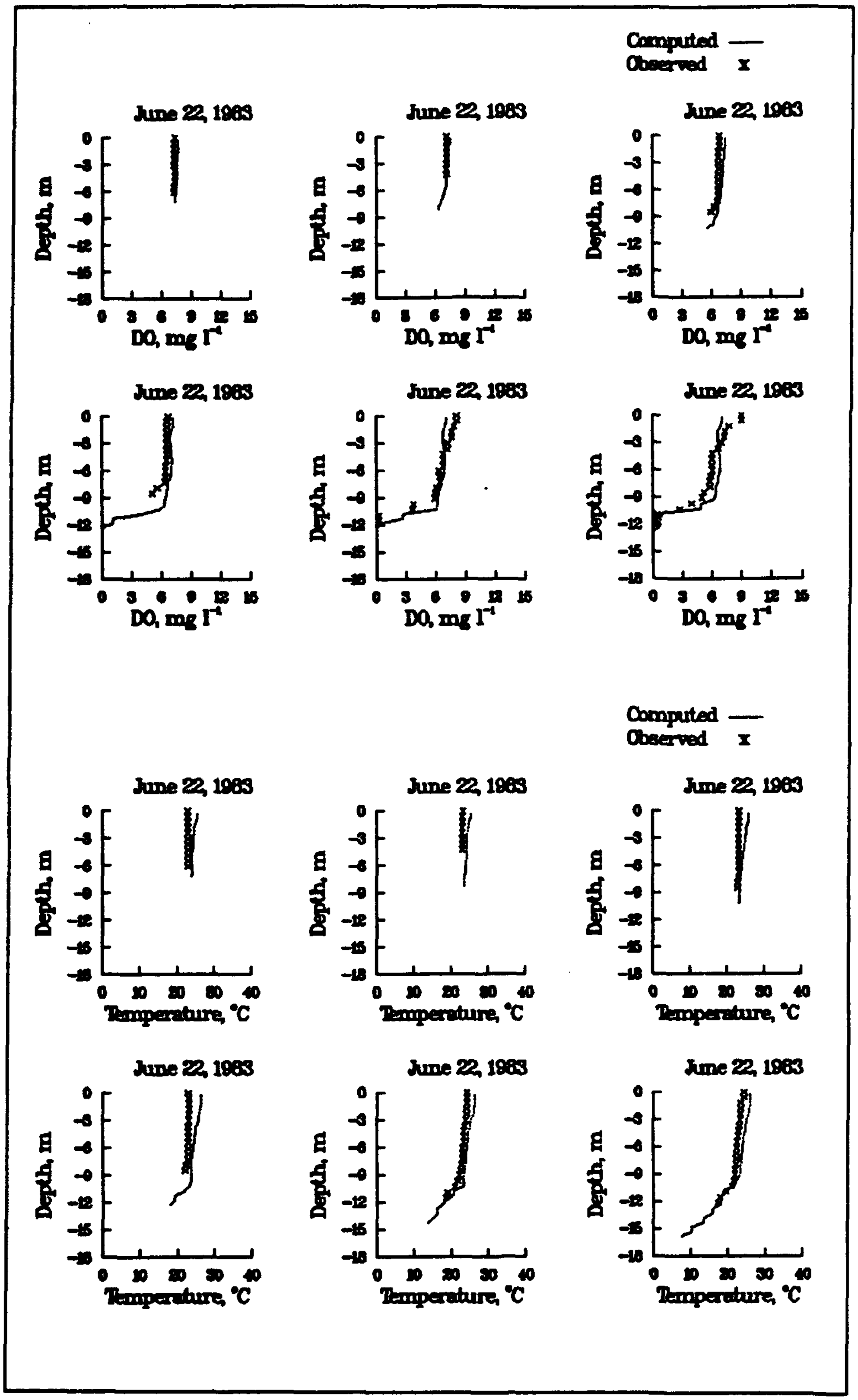

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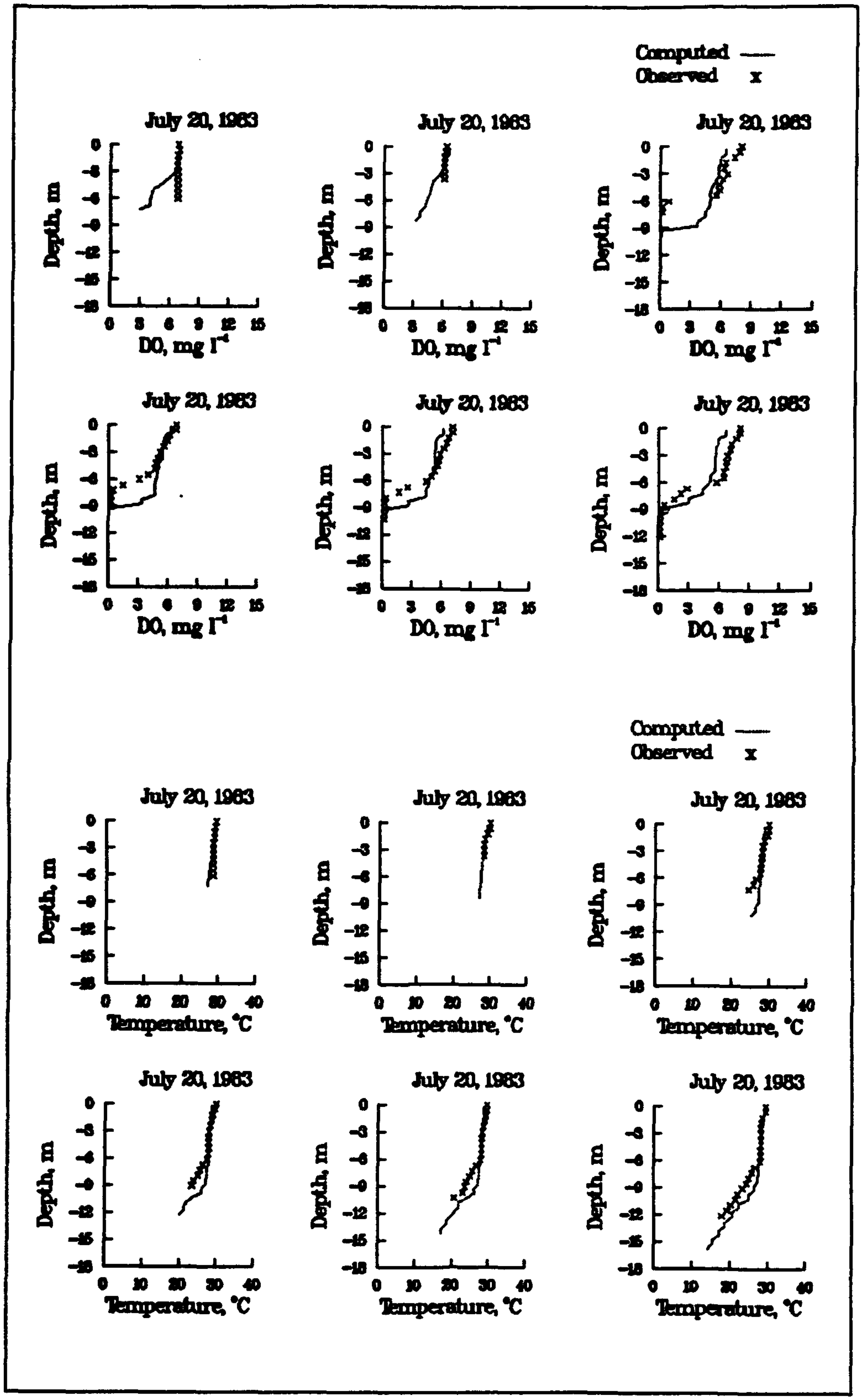

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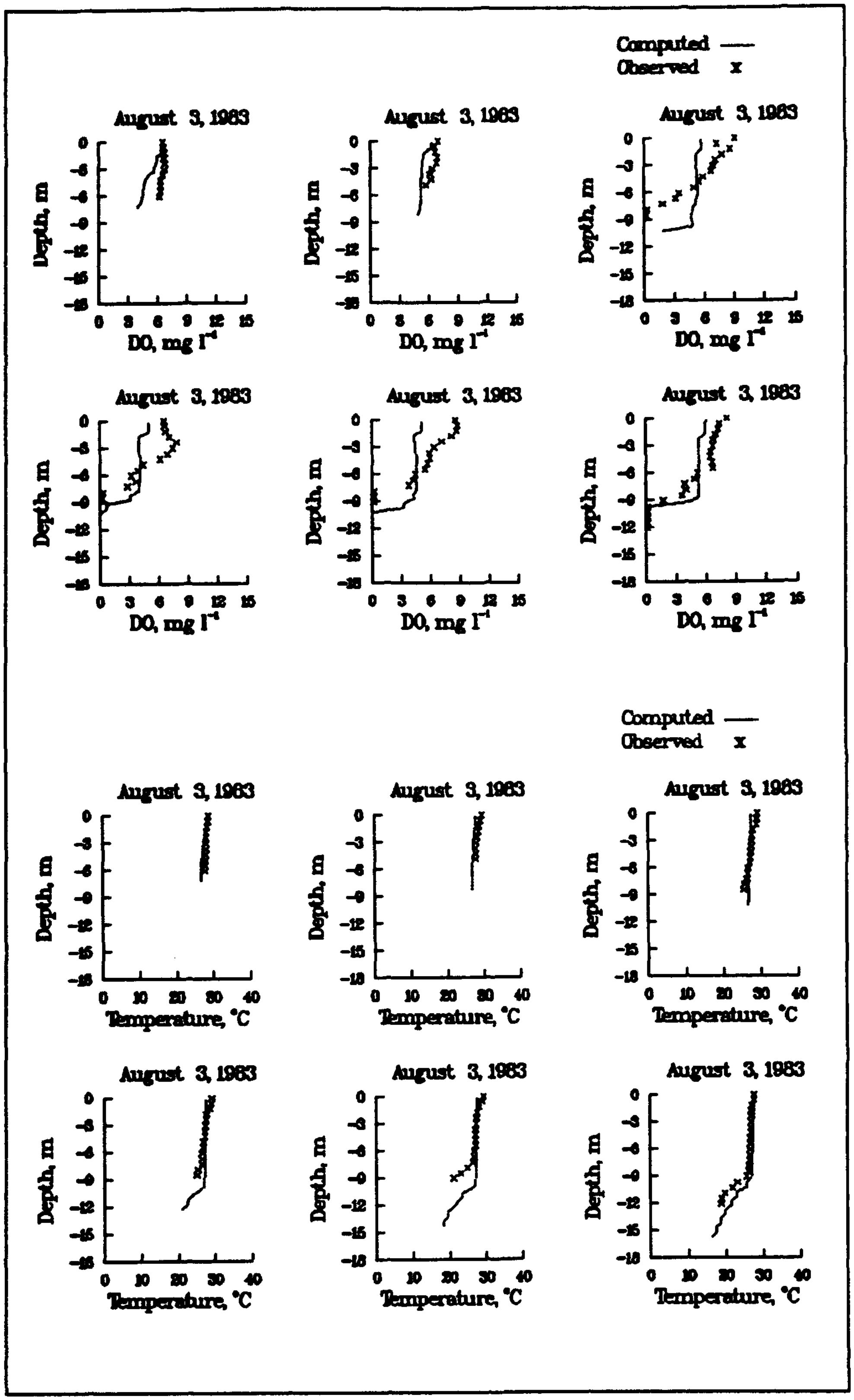

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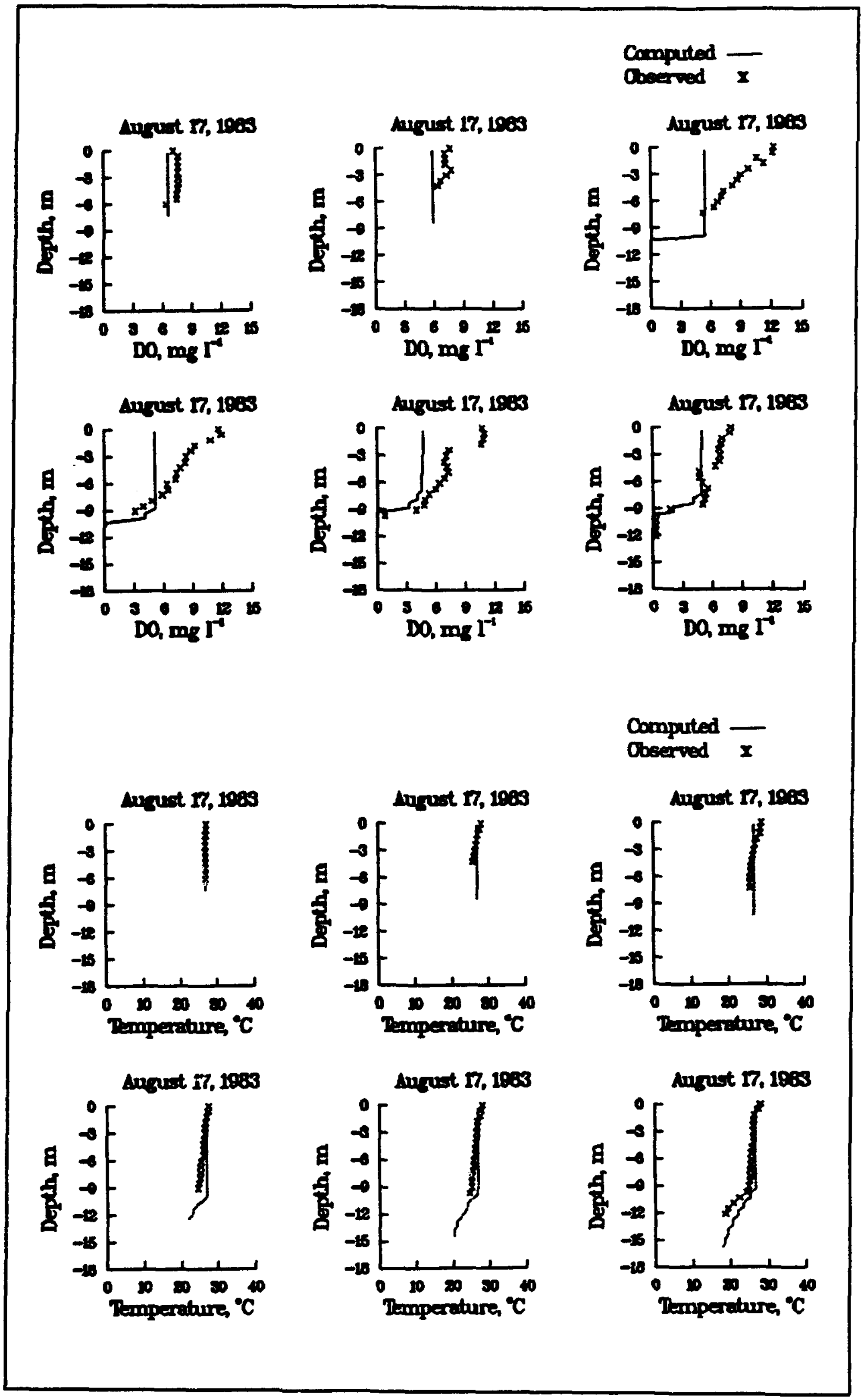

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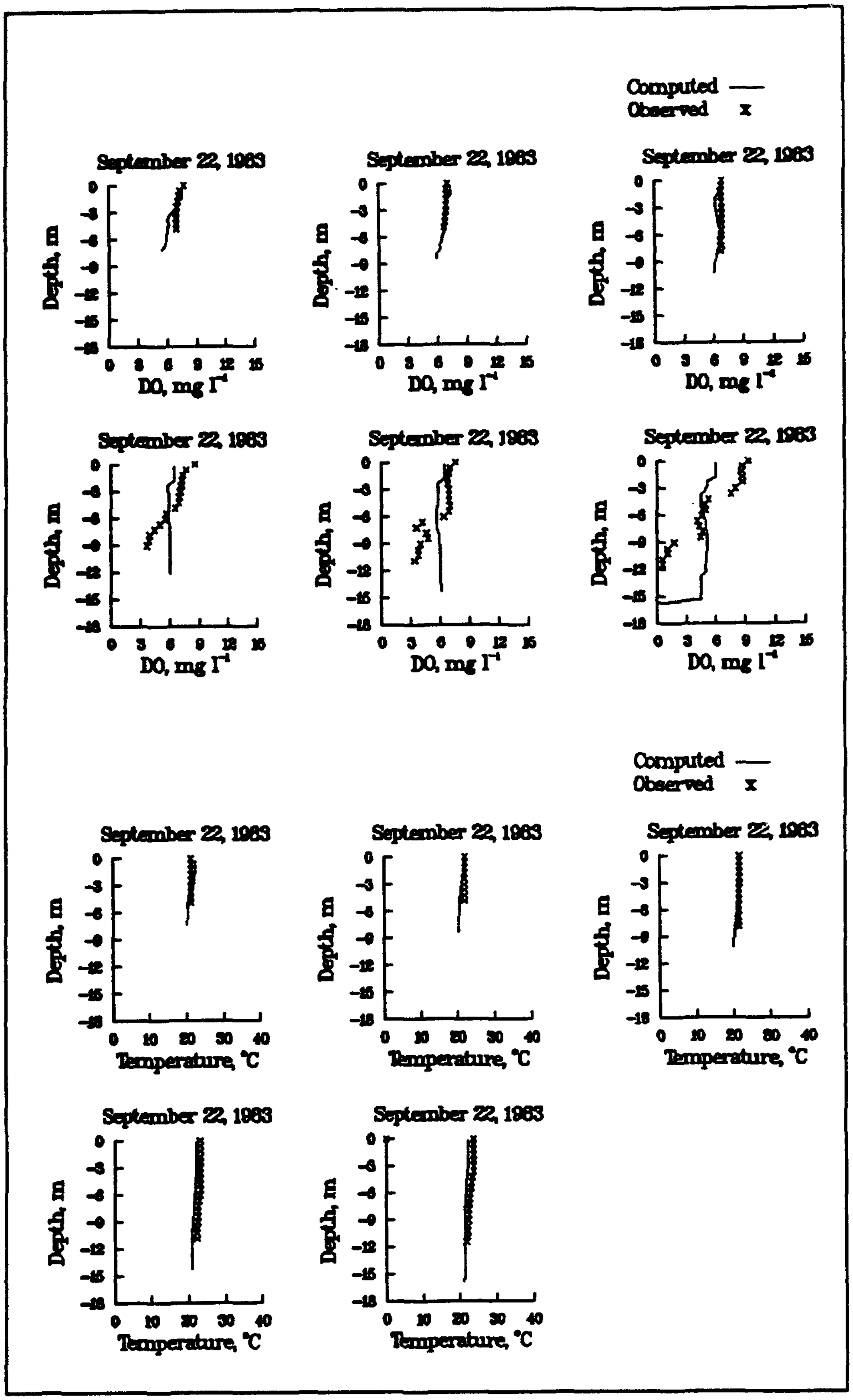

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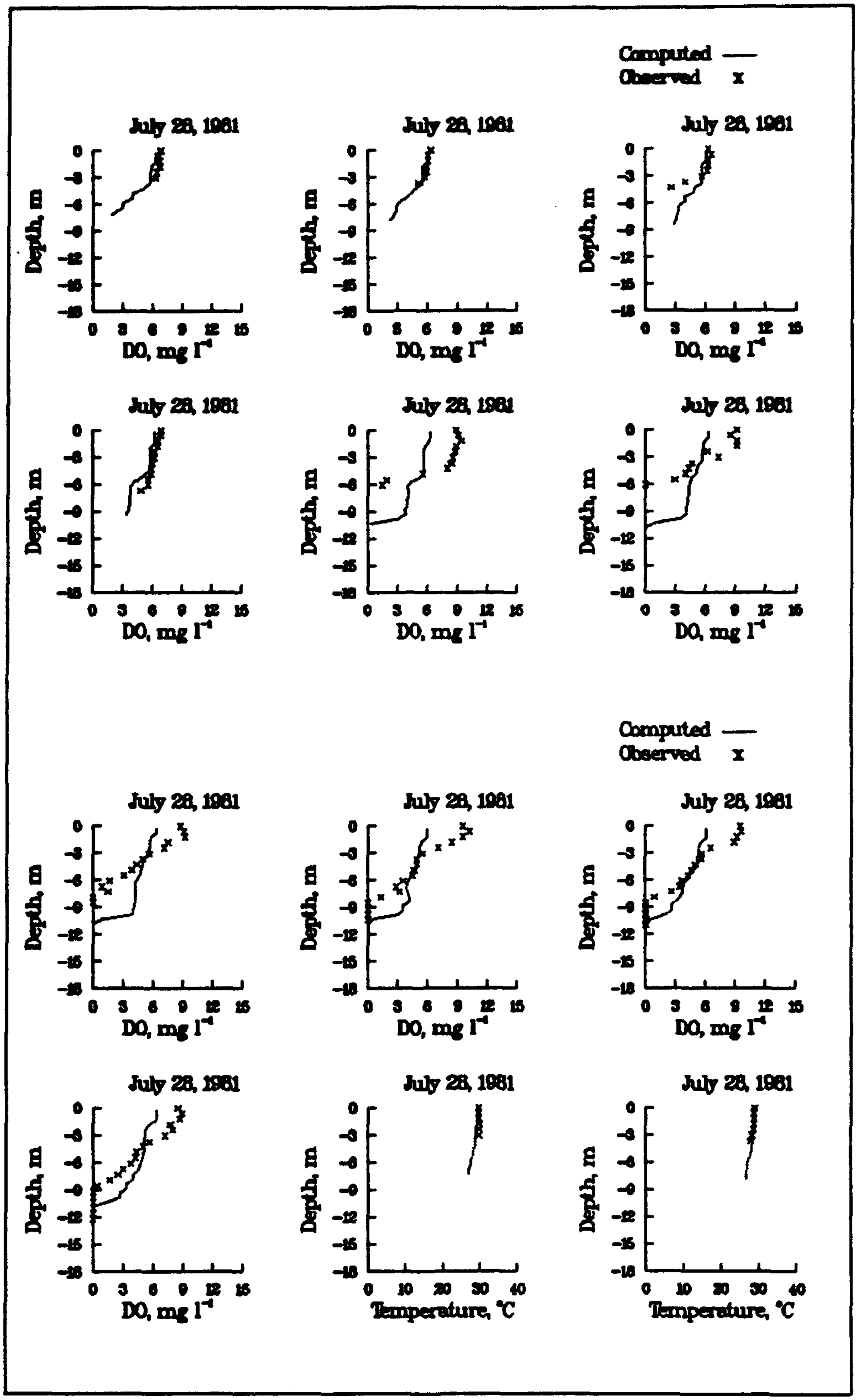
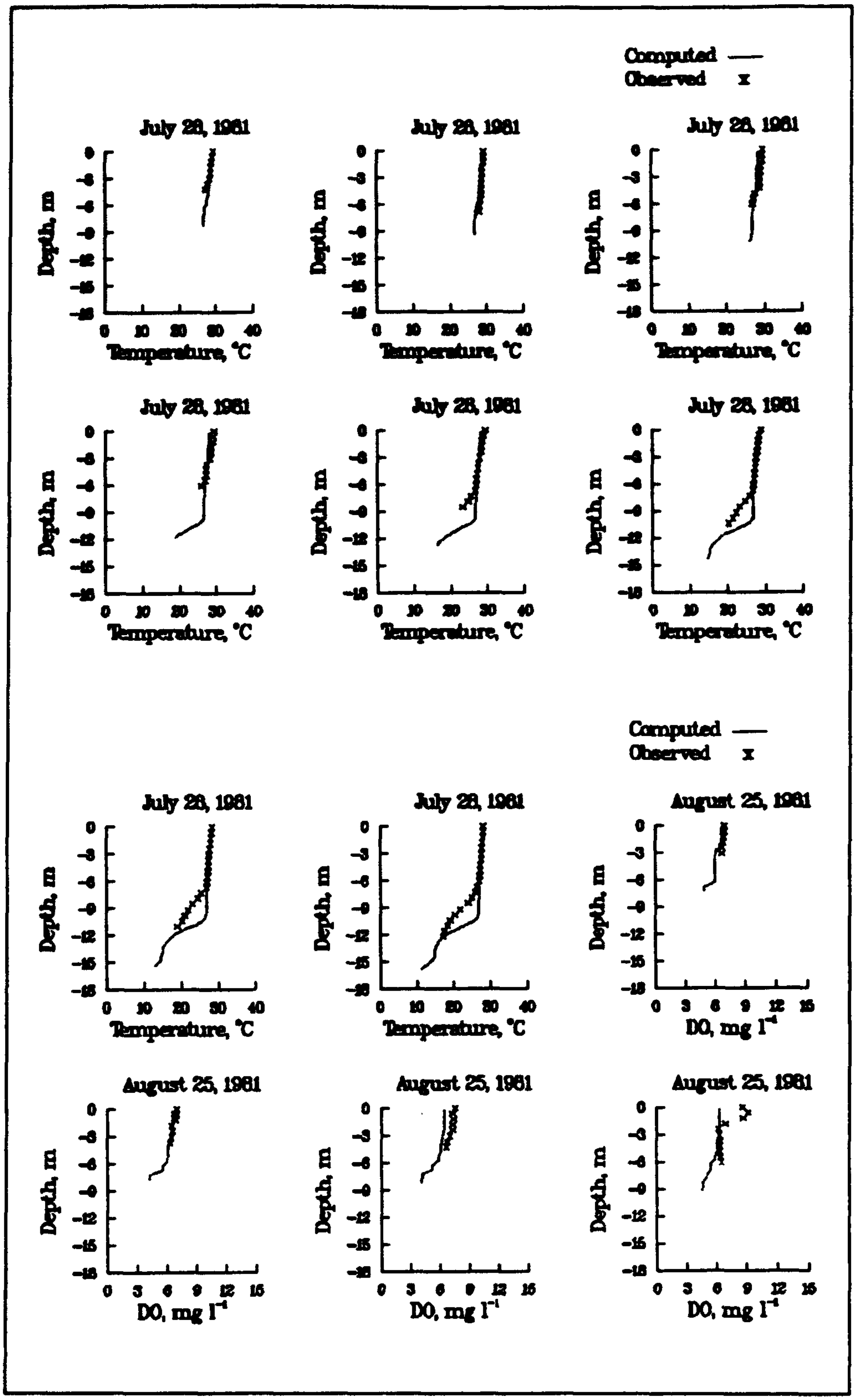


Figure C2. Scenario 2 results from increasing pool 11 ft and adding hydropower for 1981 and 1983 (Sheet 1 of 10)



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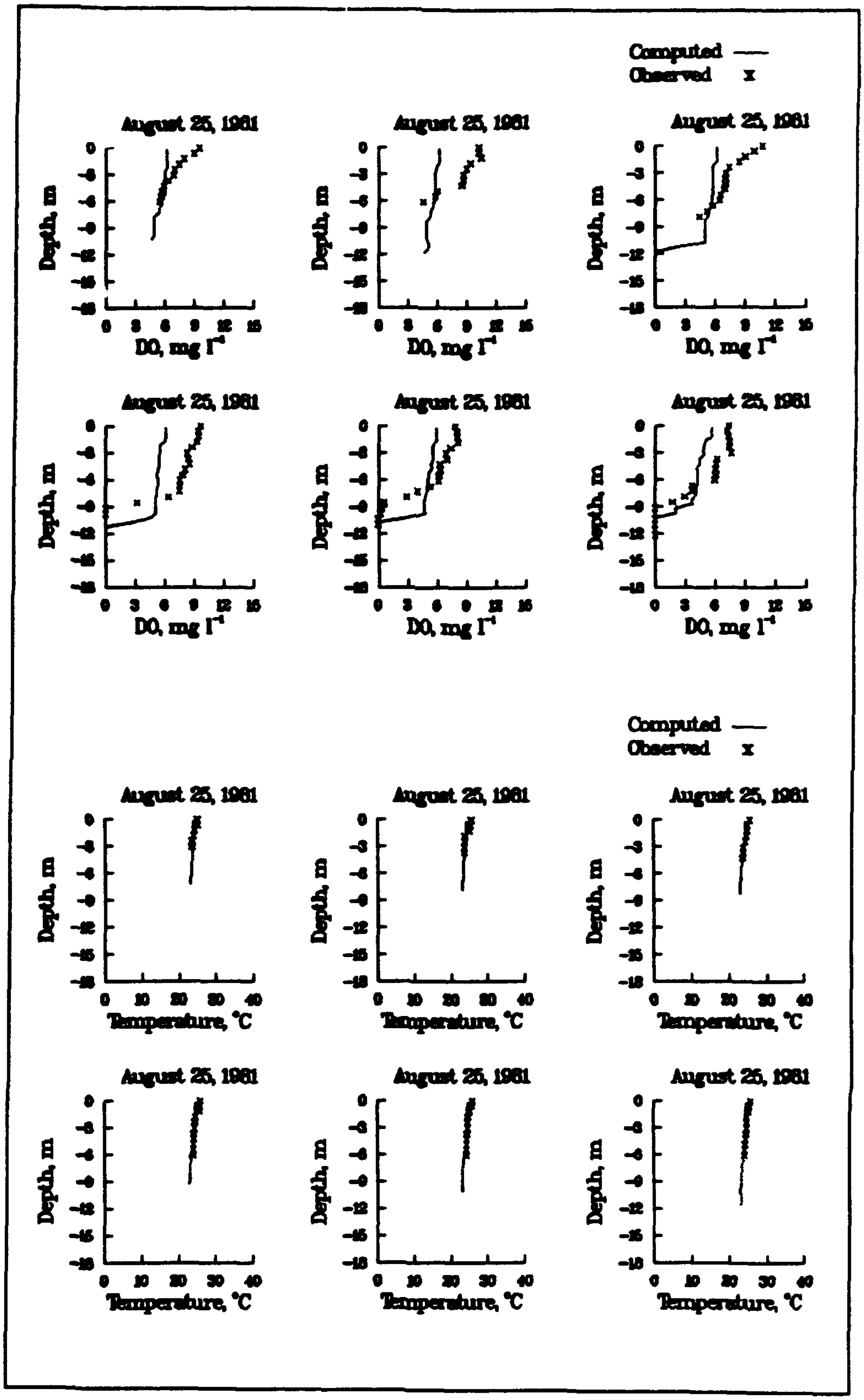

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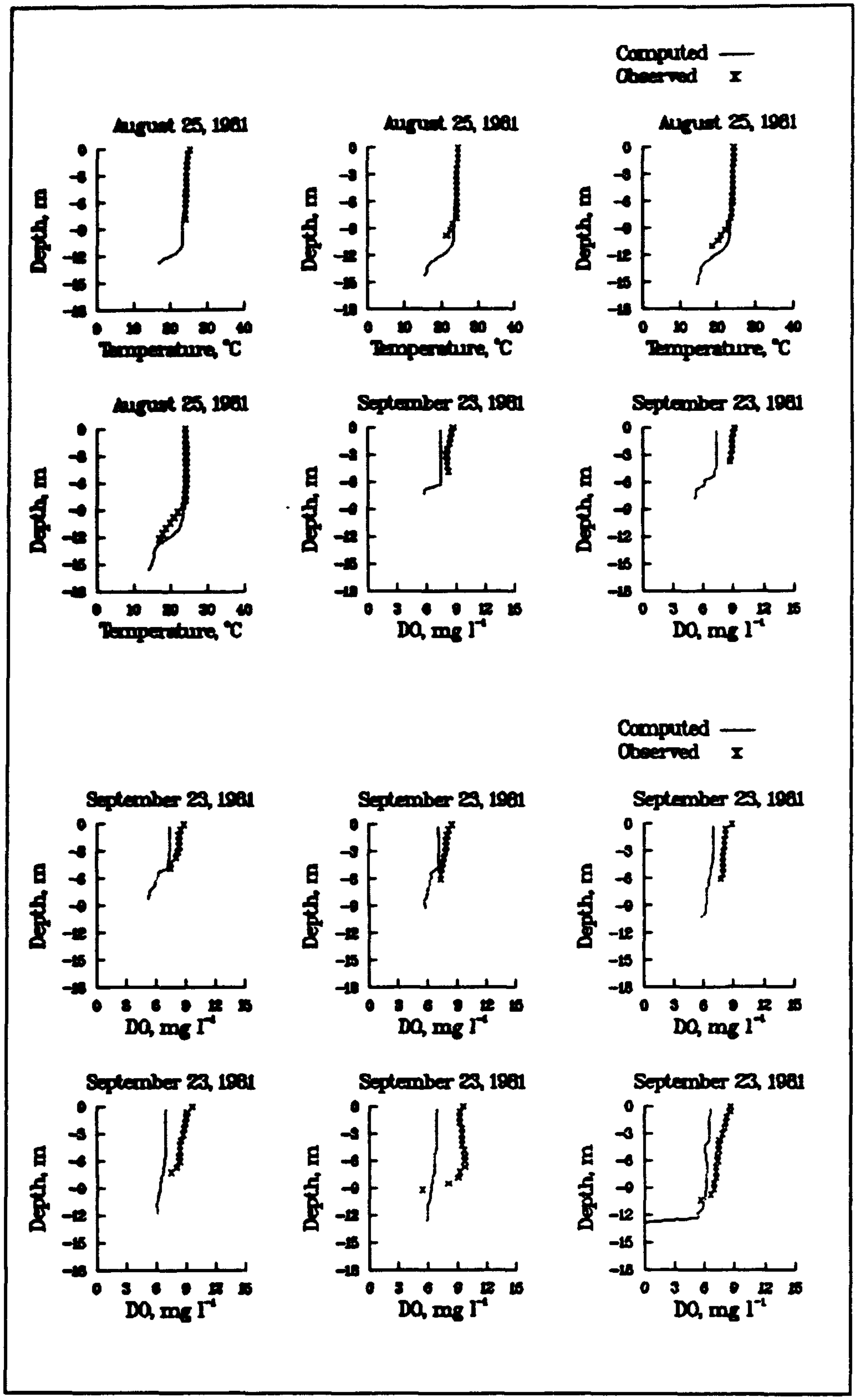

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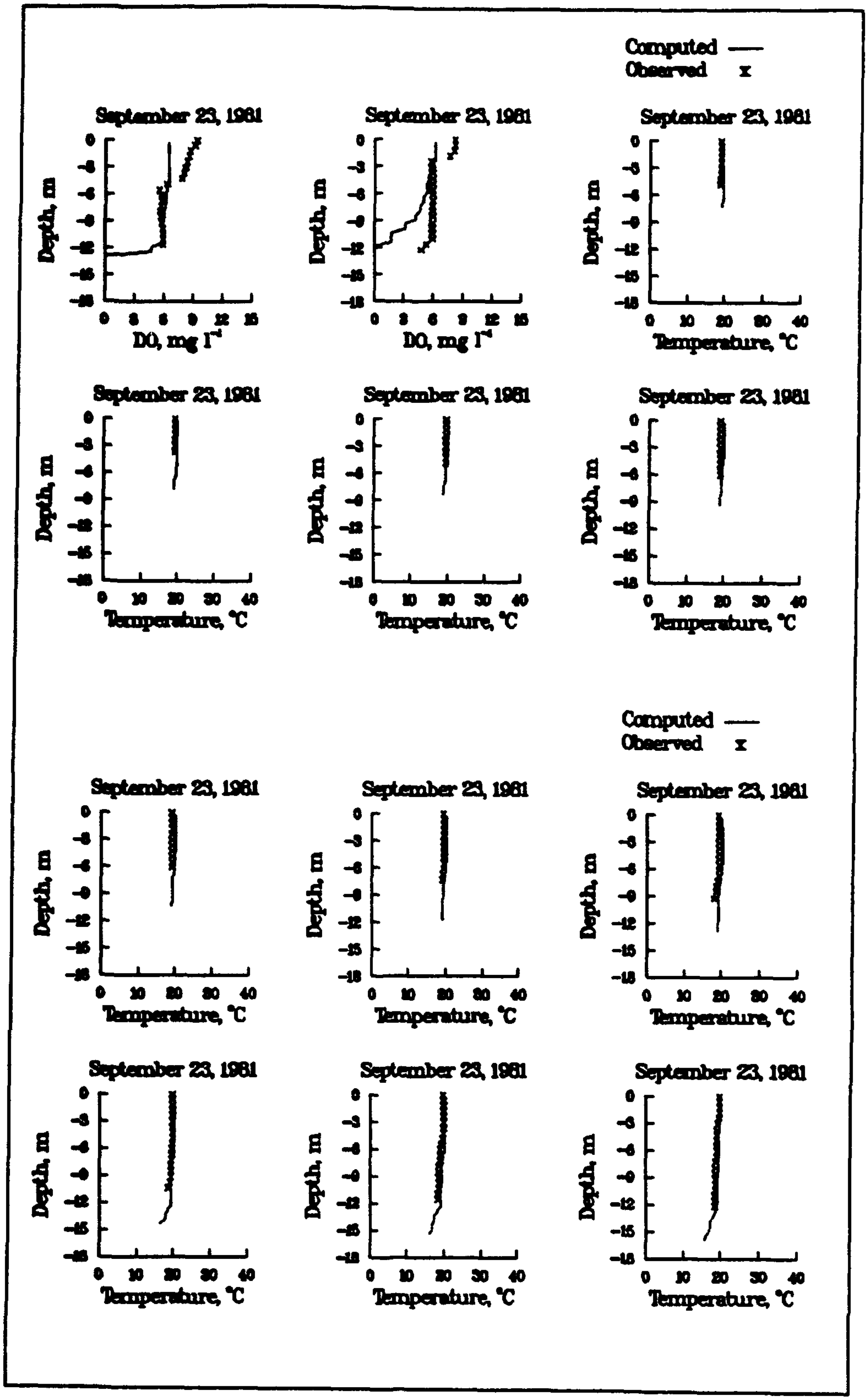

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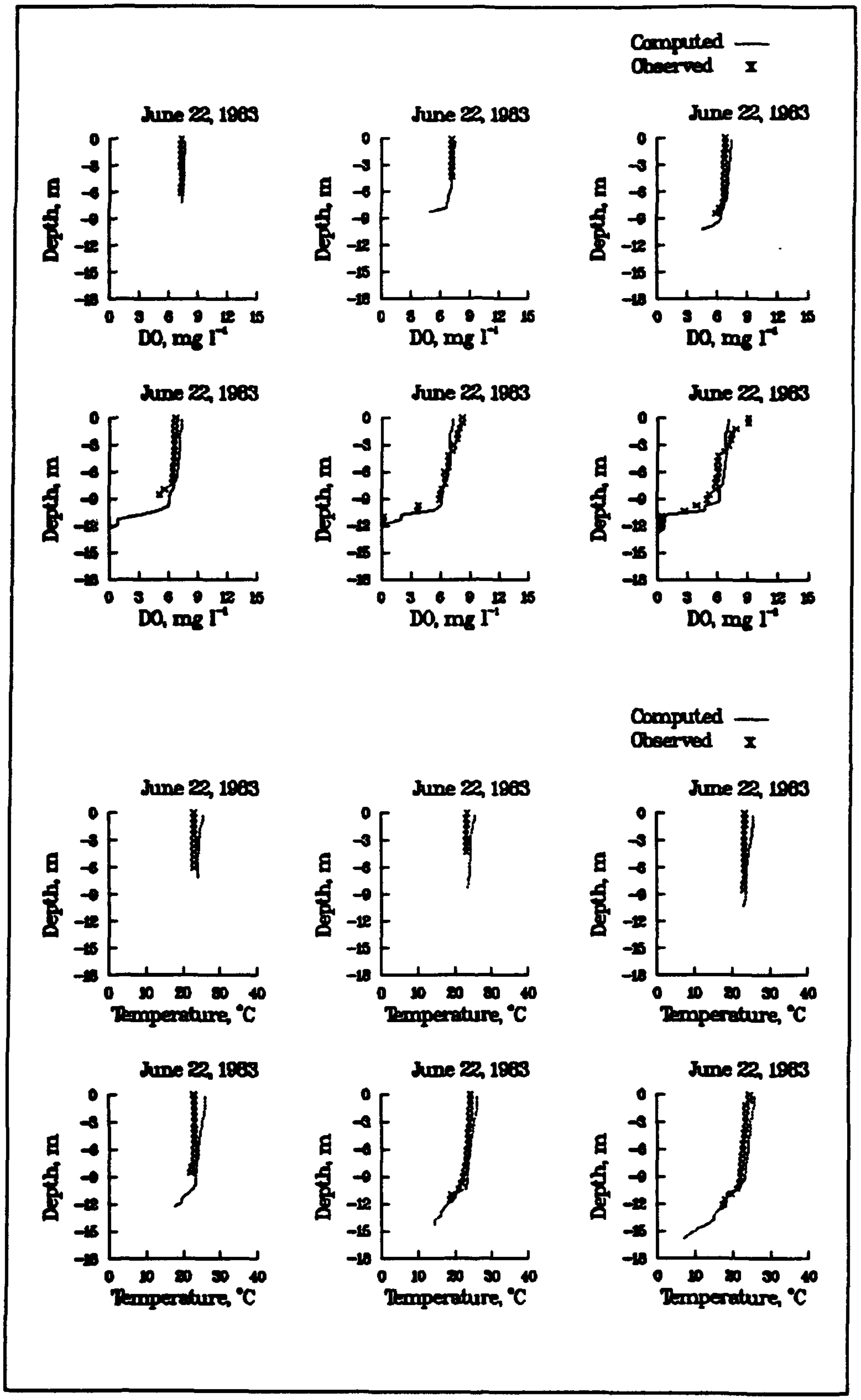

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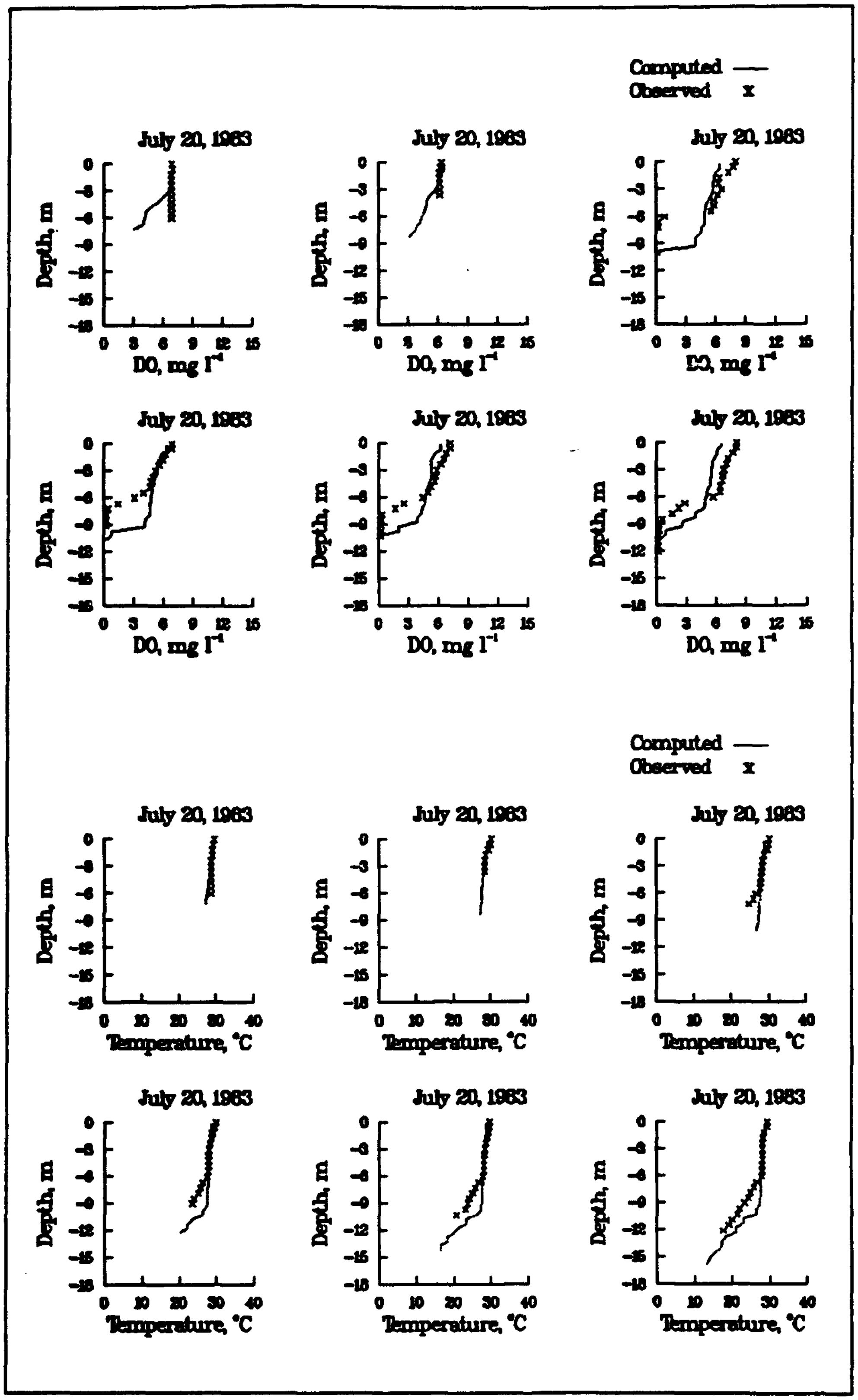

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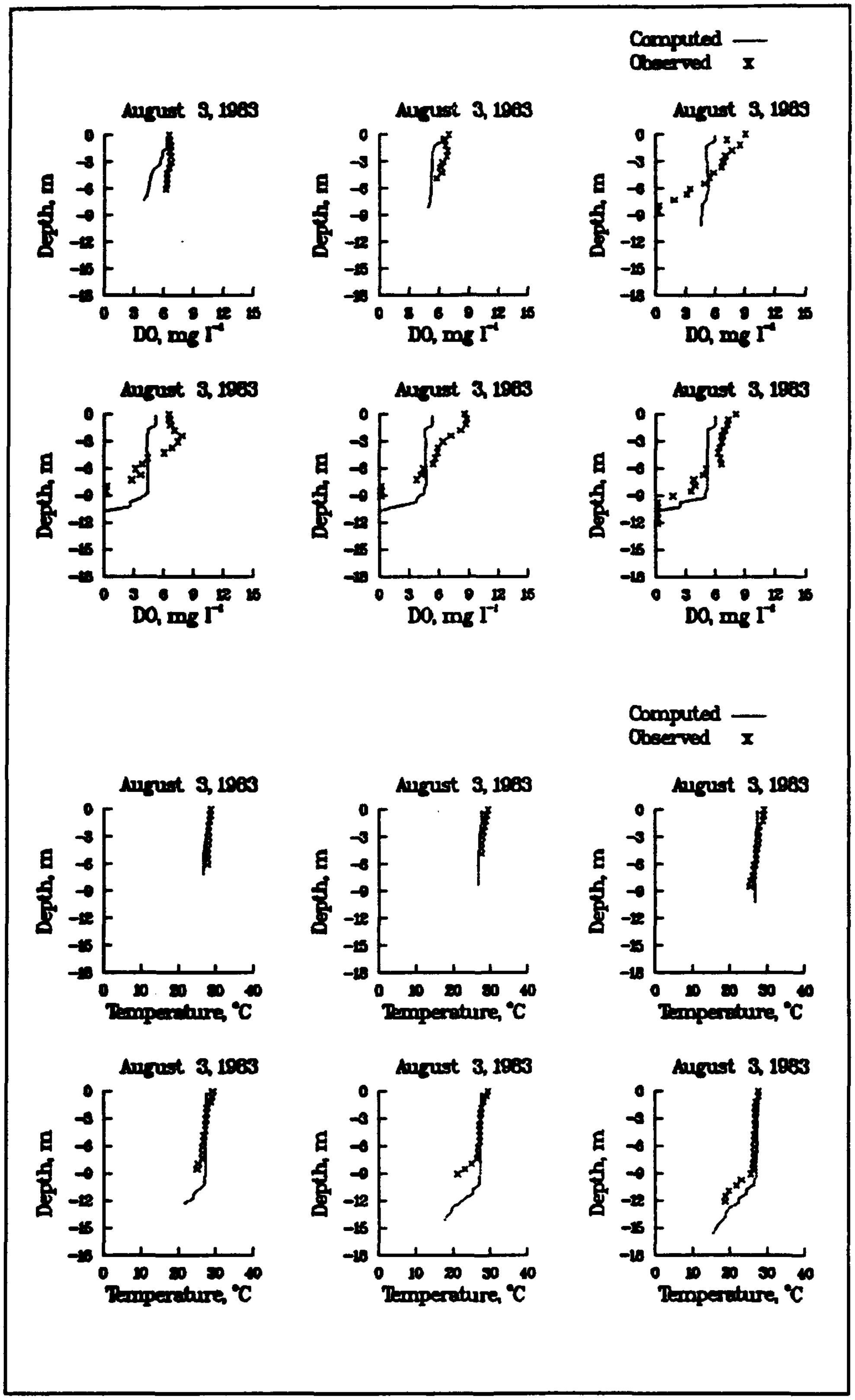

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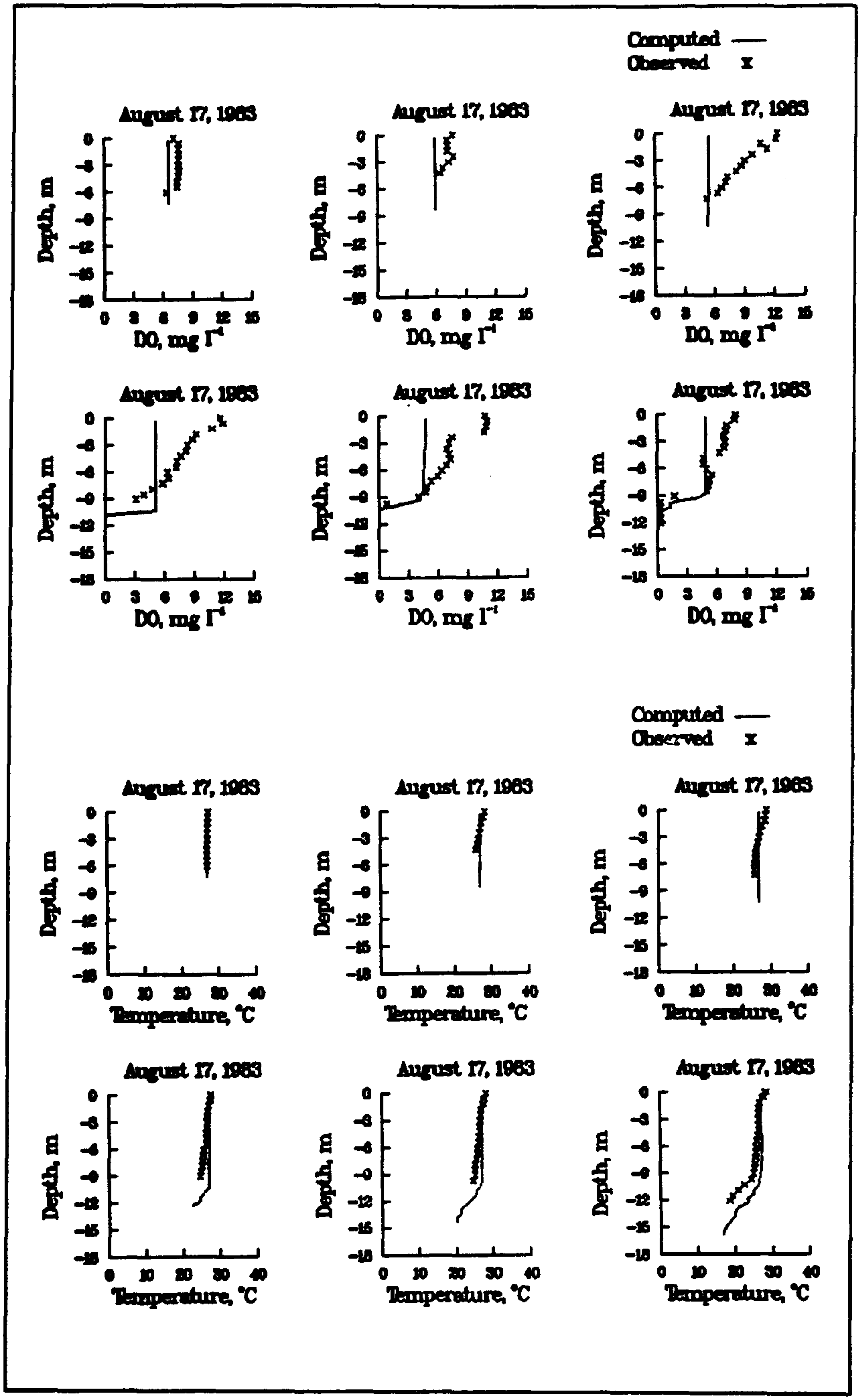

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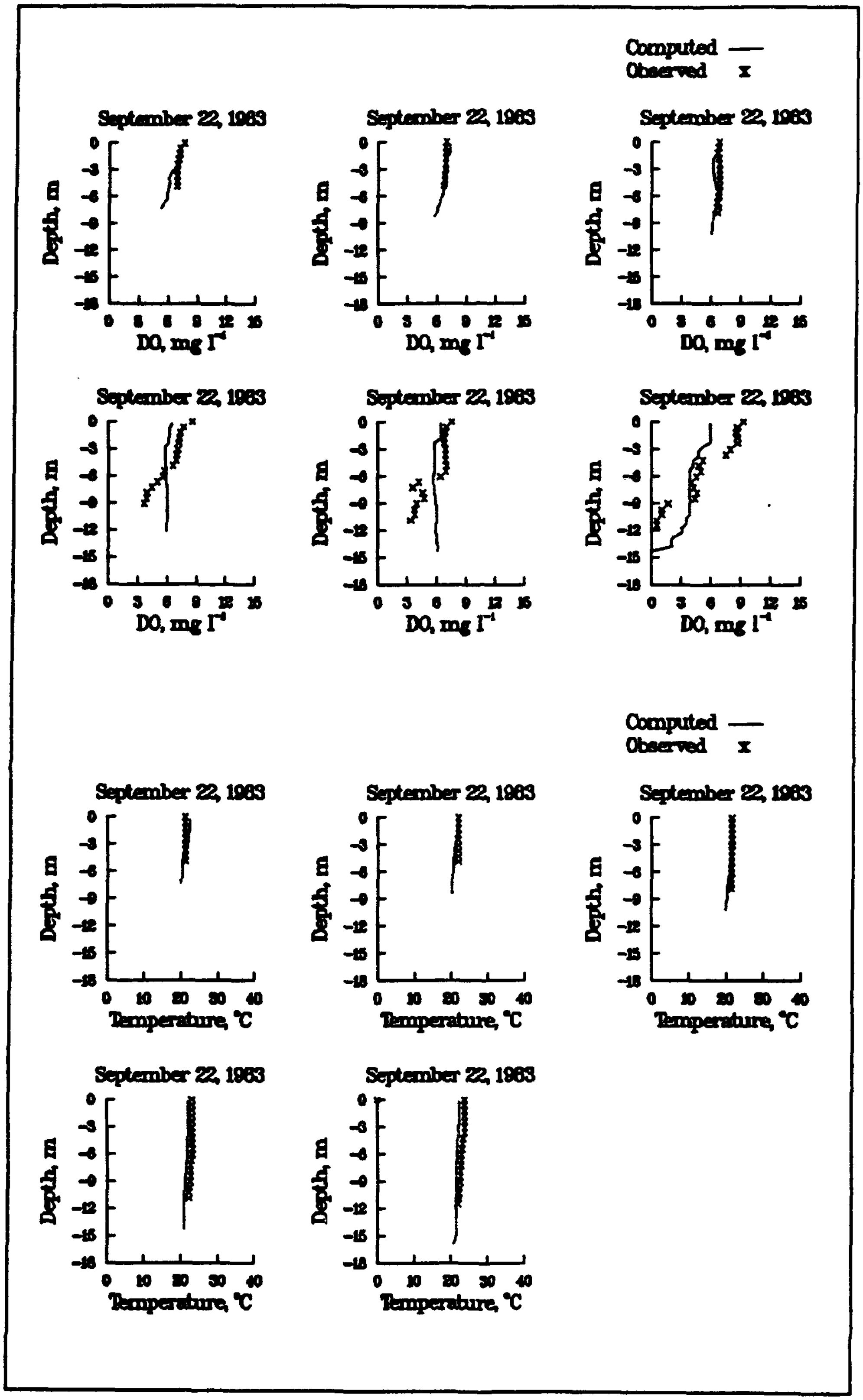

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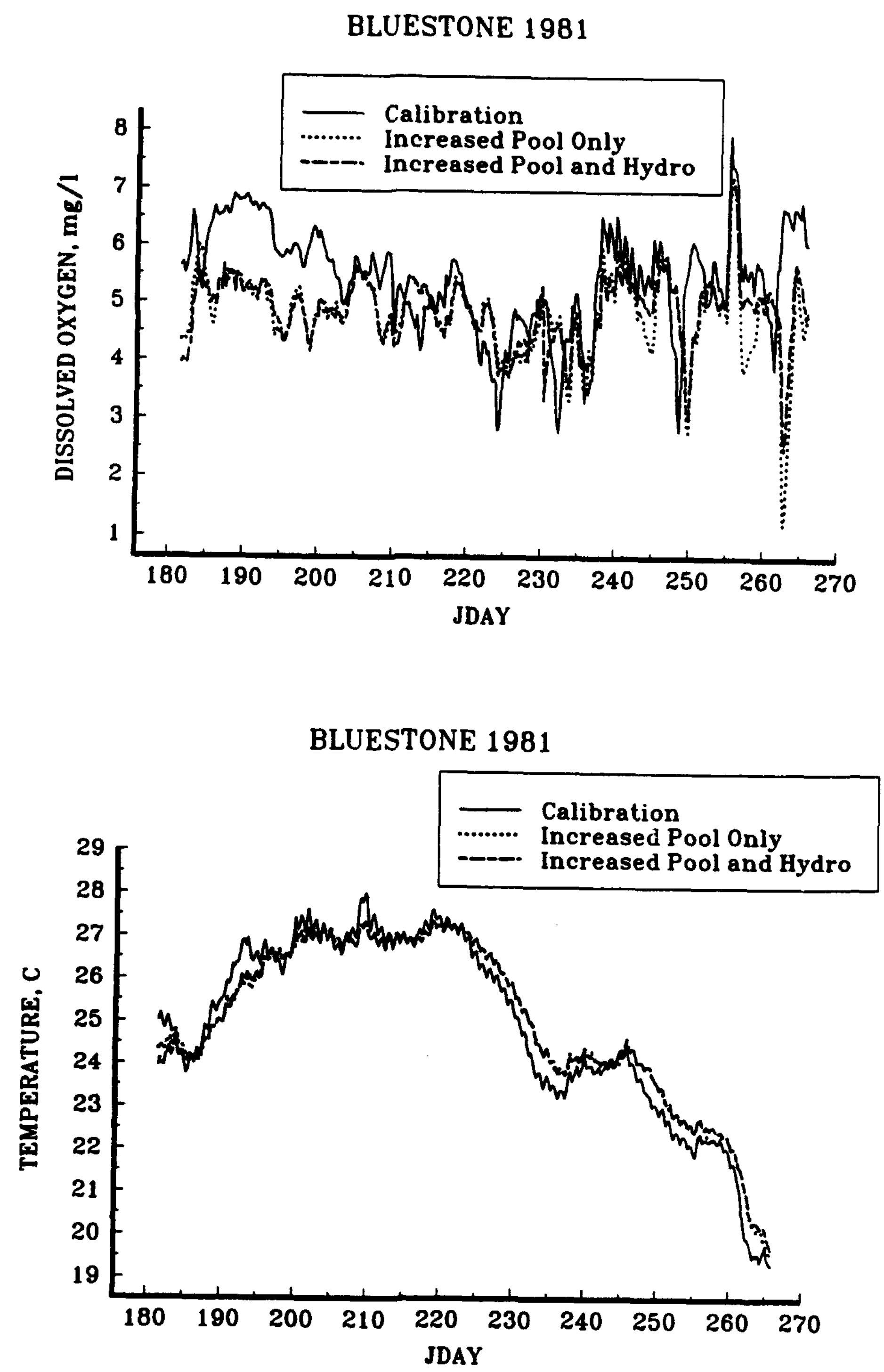

Figure C3. Comparison plots of DO and temperature calibration, Scenario 1, and Scenario 2 results (1981)

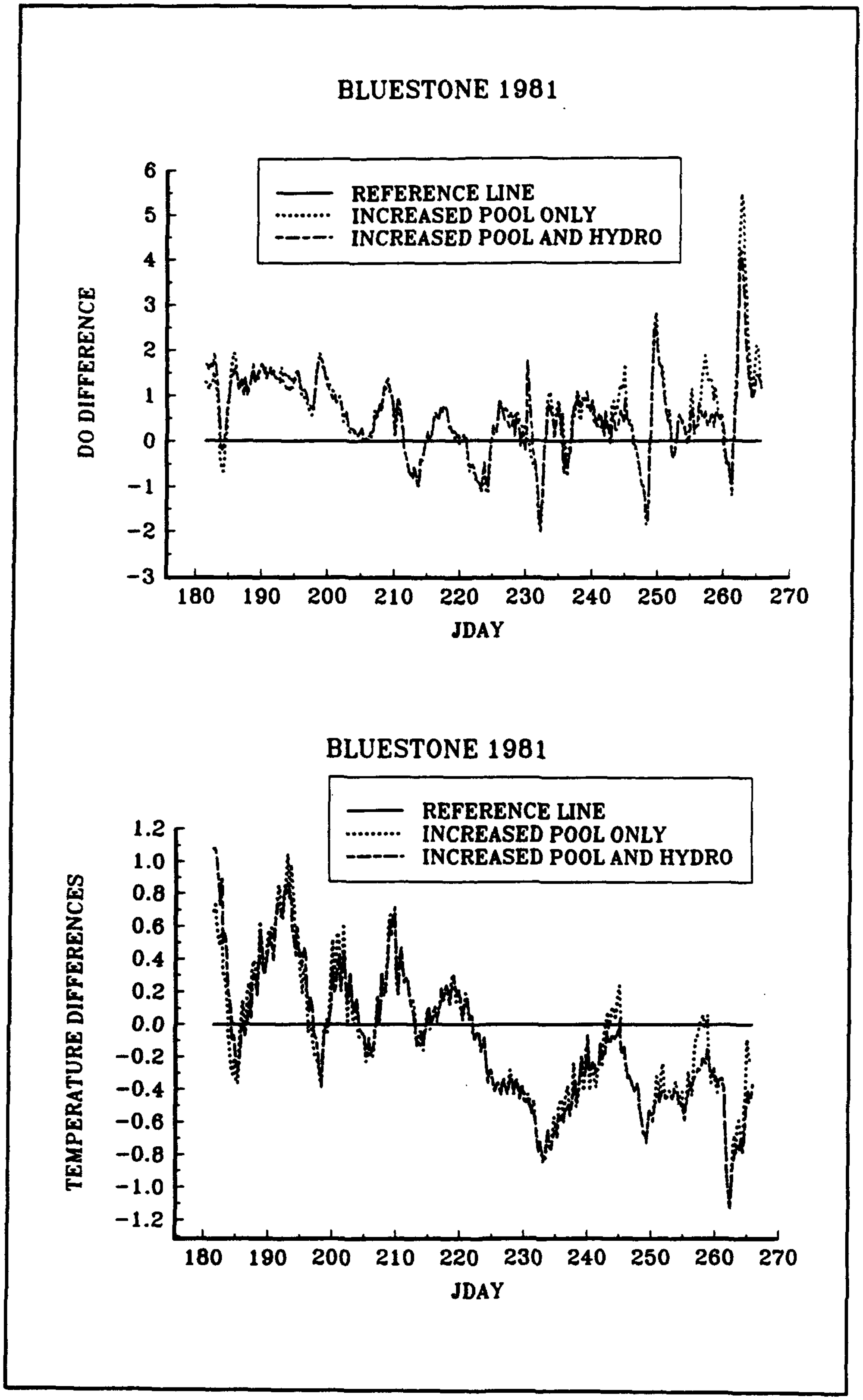

Figure C4. DO and temperature differences between calibration results and both scenario results

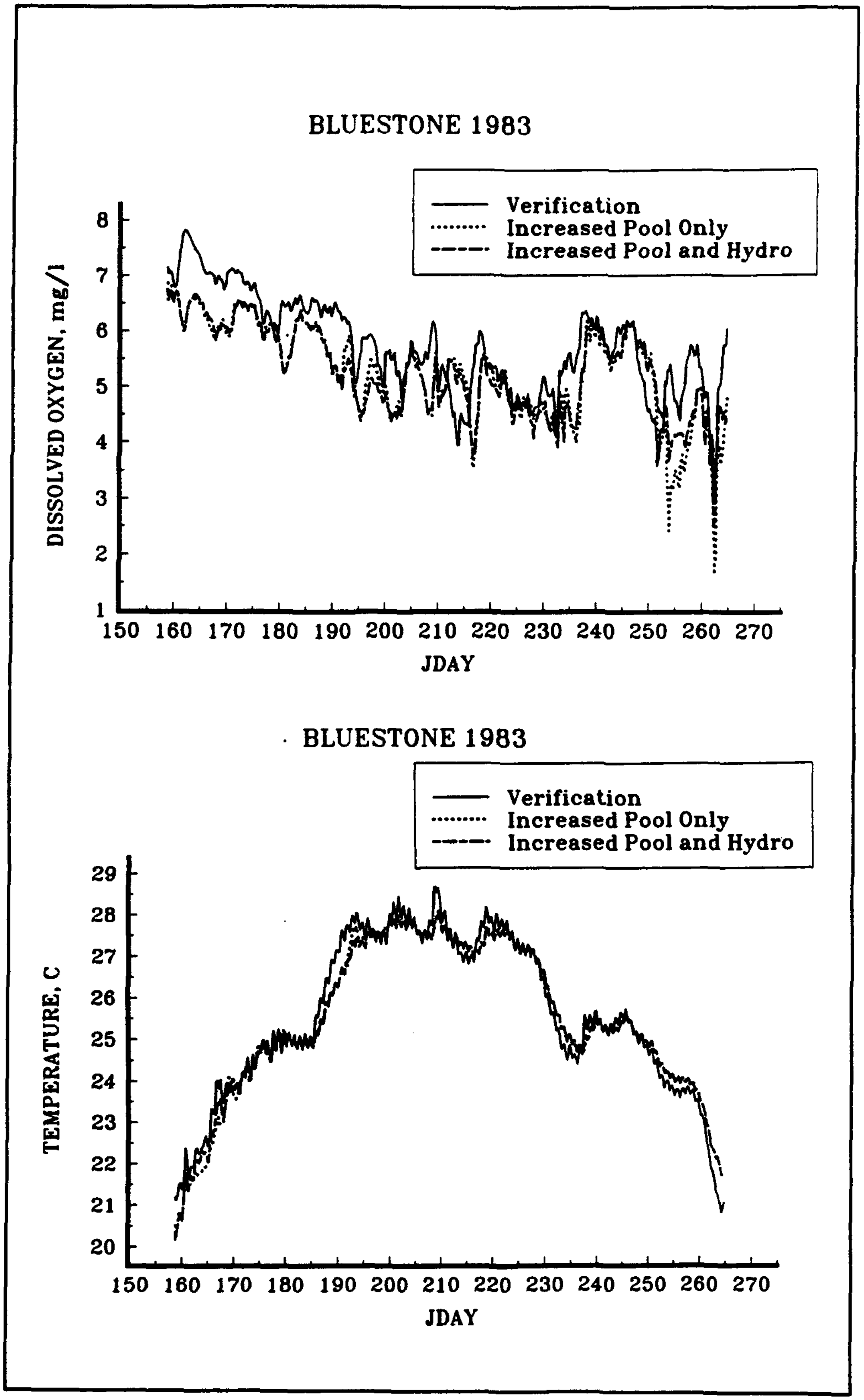

Figure C5. Comparison plots of DO and temperature verification, Scenario 1, and Scenario 2 results (1983)

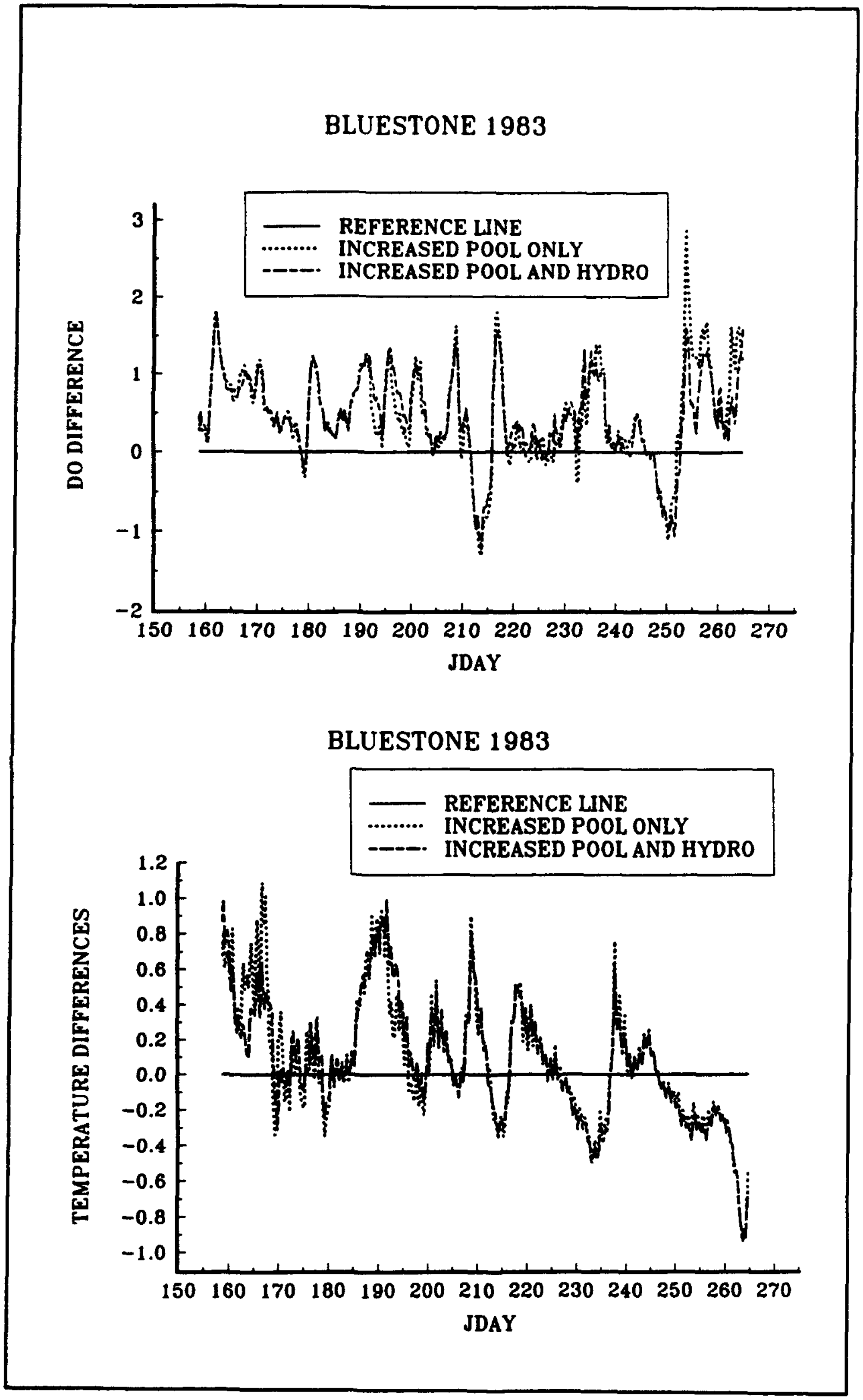

Figure C6. DO and temperature differences between verification results and both scenario results

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13. ABSTRACT *(Maximum 200 words)*

The U.S. Army Engineer District, Huntington, is considering raising the pool 11 ft at Bluestone Lake and adding conventional hydropower to the project. The Huntington District requested assistance from the U.S. Army Engineer Waterways Experiment Station to determine the effects these changes would have on in-pool and release temperature and dissolved oxygen (DO) of Bluestone Lake. CE-QUAL-W2, the Corps two-dimensional (laterally averaged) reservoir hydrodynamic and water quality model, was chosen to evaluate the effects. Because other water quality constituents were not modeled, DO was modeled in a simplified manner using a gross water column oxygen demand and a sediment oxygen demand. The model was calibrated and verified for a wet and dry hydrology. After calibration/verification, two scenarios were run looking at (a) raising the pool 11 ft only and (b) raising the pool and adding hydropower. Results indicate that Scenario 1 would cause changes in in-pool and release temperature and DO. Adding hydropower (Scenario 2) did not significantly affect in-pool and release temperature and DO results when compared with Scenario 1 results.

14. SUBJECT TERMS

Dissolved oxygen	Sediment oxygen demand	Water quality
Hydropower	Temperature	
Modeling	Water column oxygen demand	

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